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# ENGINEERING CHEMISTRY (22CH101)

| | |
|---|---|
| DEPARTMENT | ADS, CSD, CSE, IT |
| BATCH/YEAR | 2022-23/I |
| CREATED BY | CHEMISTRY DIVISION |
| DATE | NOVEMBER 2022 |

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# COURSE OBJECTIVES

**Objectives:**

The goal of this course is to achieve conceptual understanding of the applications of chemistry in engineering and technology. The syllabus is designed to:

- To understand the water quality criteria and interpret its applications in water purification.
- To gain insights on the basic concepts of electrochemistry and implement its applications in Chemical Sensors.
- To acquire knowledge on the fundamental principle of energy storage devices and relate it to Electric Vehicles.
- To identify the different types of smart materials and explore its applications in Engineering and Technology.
- To assimilate the preparation, properties and applications of nanomaterials in various fields.

## 22CH101-ENGINEERING CHEMISTRY L T P C 3 0 2 4

## UNIT II ELECTROCHEMISTRY AND SENSORS 15

Introduction- Conductance- factors affecting conductance – Electrodes – origin of electrode potential – single electrode potential, standard electrode potential – measurement of single electrode potential –over voltage - reference electrodes (standard hydrogen electrode, calomel electrode)-ion selective electrode- glass electrode - Nernst equation (derivation), numerical problems, Electrochemical series and its applications.

Chemical sensors – Principle of chemical sensors – Breath analyzer – Gas sensors – $CO_2$ sensors- Sensor for health care – Glucose sensor.

**Lab Experiments:**

**1. Determination of the amount of NaOH using a conductivity meter.**

**2. Determination of the amount of acids in a mixture using a conductivity meter.**

**3. Determination of the amount of given hydrochloric acid using a pH meter.**

## COURSE OUTCOMES

| COs | Outcomes |
|---|---|
| **CO 1** | Interpret the water quality parameters and explain the various water treatment methods. |
| **CO 2** | Construct the electrochemical cells and sensors. |
| **CO 3** | Compare different energy storage devices and predict its relevance in Electric Vehicles. |
| **CO 4** | Classify different types of smart materials, their properties and applications in engineering and technology. |
| **CO 5** | Integrate the concepts of nano chemistry and enumerate its applications in various fields. |

## Course Outcome mapping with POs / PSOs

| COs | PO1 | PO2 | PO3 | PO 4 | PO5 | PO 6 | PO7 | PO 8 | PO 9 | PO10 | PO11 | PO12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO1 | 3 | 2 | | | | 2 | 2 | | | | | 1 |
| CO2 | 3 | 2 | | | | 1 | 1 | | | | | 1 |
| CO3 | 3 | 2 | | | | 2 | 1 | | | | | 1 |
| CO4 | 3 | 2 | | | | 1 | 1 | | | | | 1 |
| CO5 | 3 | 2 | | | | 1 | 1 | | | | | 1 |

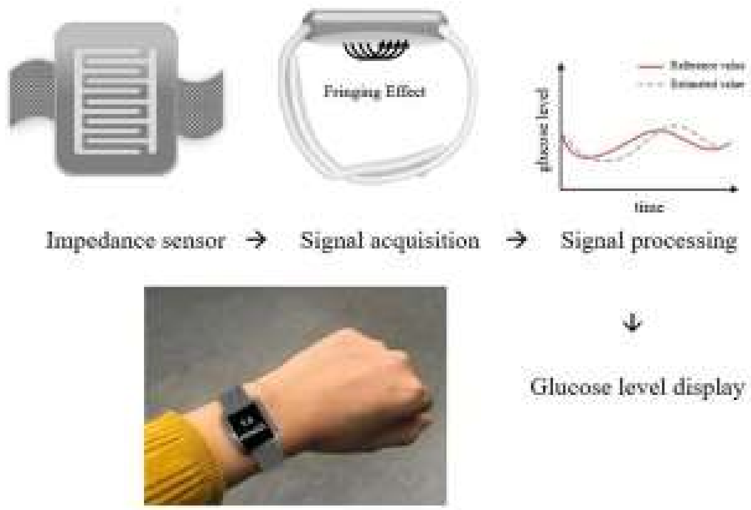
# LECTURE PLAN dd

| S. No . | Topics to be covered | No. of periods | Proposed date | Actual lecture date | CO | Taxonomy level | Mode of delivery |
|---|---|---|---|---|---|---|---|
| 1 | Introduction –conductance- factors affecting conductance – Electrodes – origin of electrode potential | 1 | | | | | |
| 2 | single electrode potential, standard electrode potential , measurement of single electrode potential, over voltage | 1 | | | | | |
| 3 | reference electrodes (standard hydrogen electrode, calomel electrode) | 1 | | | | | |
| 4 | Ion selective Electrode, Glass Electrode | 1 | | | | | |
| 5 | Nernst equation (derivation) and numerical problems | 1 | | | | | |
| 6 | Electrochemical series and its applications | 1 | | | | | |
| 7 | Principle of chemical sensors – Breath analyzer | 1 | | | | | |
| 8 | Gas sensors, CO2 sensors- | 1 | | | | | |
| 9 | Sensor for health care – Glucose sensor. | 1 | | | | | |
| 10 | Determination of the amount of NaOH using a conductivity meter. | 2 | | | | | |
| 11 | Determination of the amount of acids in a mixture using a conductivity meter. | 2 | | | | | |
| 12 | Determination of the amount of given hydrochloric acid using a pH meter. | 2 | | | | | |

## ACTIVITY BASED LEARNING

| Activity | Topics | Outcomes |
|---|---|---|
| Group discussion | Glucose sensor | <u>Students will learn:</u><br>• Glucose sensors and their working principle |
| Making of saltwater pentacell | Saltwater pentacell and its reaction | <u>Students will learn:</u><br>• Construction and working of five simple cells (electrochemical cells) using copper, aluminium and saltwater |
| Coating of Metal on a non-conductor by electroless deposition method | Electroless deposition | <u>Students will learn:</u><br>• Construction and working of electrochemical reaction by electroless deposition method |

## Glucose sensors




## Activity 1: Saltwater Pentacell

**Principle:** Converting electric energy into light.

**Materials required:** Insulated stranded copper wire, ruler or measuring tape,wire strippers

Scissors, about 8 inches (20 cm) of aluminum foil from a normal 12-inch-wide (30 cm) roll

Pitcher or bowl with a spout, 1 quart (1 L) of water, 2 tablespoons (30 mL) of table salt (sodium chloride), stirring spoon, five plastic cups, six alligator-clip leads about 12 inches long,

red light-emitting diode (LED), 1 tablespoon (15 mL) of vinegar (acetic acid)

**Assembly:**

•Cut the stranded copper wire into five sections of 4 inches (10 cm) each

•Cut five pieces of aluminum foil, each about 4 x 4 inches (10 x 10 cm) square

•Add the salt to the water and stir

•Fill each plastic cup about three-quarters full of the electrolyte solution.

**Working:**

The positive sodium ions are attracted to the negative copper electrode, where they participate in neutralizing the extra negative charge through chemical reactions. Likewise, the negative chloride ions are attracted to the positive aluminum electrode, where they participate in neutralizing the extra positive charge. Therefore, there's a constant flow of charge from one electrode through the LED to the other electrode and then through the electrolyte solution, forming a complete circuit.

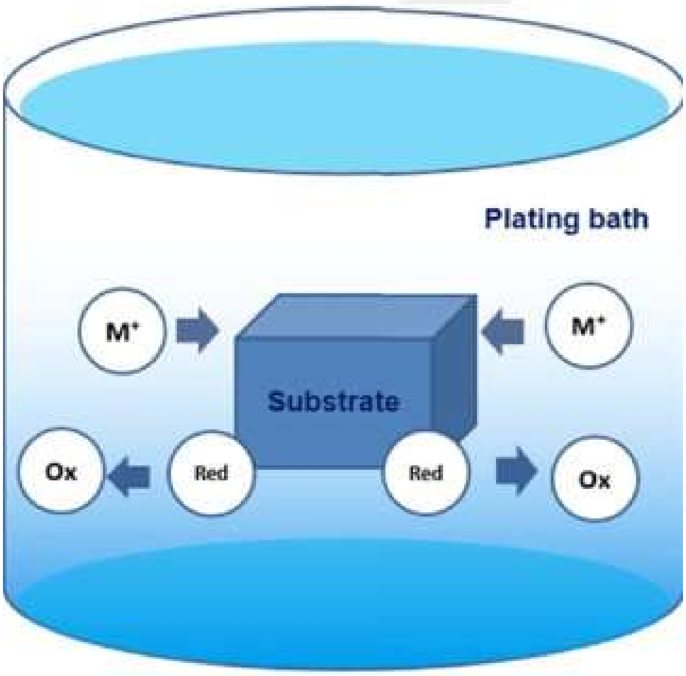
## Activity 2: Coating of Metal on a non-conductor by electroless deposition method

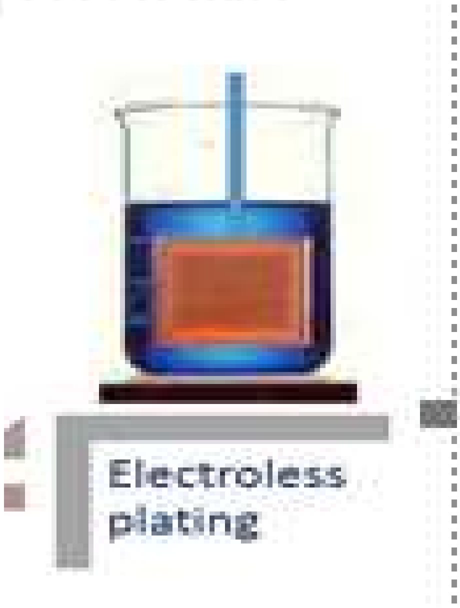
| | |
|---|---|
| STEP 1 → | Plating substrate is degreased with acetone to remove oil and grease. |
| STEP 2 → | Dipped in Dilute Sulphuric acid to coarsen and make the substrate hydrophilic for better adhesion. |
| STEP 3 → | Rinsed in distilled water |
| STEP 4 → | Sensitization is done by dipping in the substrate in a mixture of $SnCl_2$ (10g / lt ) + Con. HCl (40ml/lt) and rinsed in distilled water |
| STEP 5 → | Activation is done by dipping the substrate in a mixture of $PdCl_2$ (0.1 g/l) and Con. HCl (10 ml/l) |
| STEP 6 → | Rinsed in distilled water to remove $Pd^{2+}$ completely as it leads to bath decomposition |
| STEP 7 → | Substrate is dried, weighed and initial weight is noted |
| STEP 8 → | The substrate is dipped in the plating solution for 30 min. Plating starts with the liberation of hydrogen bubbles |
| STEP 9 → | After plating the substrate is rinsed, dried and reweighed |

## Plating Bath Components and its Functions

| COMPONENTS | FUNCTIONS |
|---|---|
| Metal Salt (E.g. $CuSO_4$ Or $CuCl_2$) | - Provides the metal ions to be plated |
| Reducing Agent (E.g. Formaldehyde, Glyoxylic Acid, Hydrazine) | - Provides the reducing power at the catalytic surface |
| Complexing Agent (TEA, EDTA) | - Complexes metal ions & prevents bulk decomposition |
| Base | - To adjust pH |
| Inhibitors/ Stabilizer | - To control reduction reaction in the plating solution |
| Accelerators | - To help increase the speed of reaction |

## Electroless Plating



# UNIT-II

# ELECTROCHEMISTRY

# UNIT-II ELECTROCHEMISTRY

## 2.1 Introduction

The branch of science which deals with the relationship between chemical energy and electrical energy is called electrochemistry. It deals with chemical reactions that involve an exchange of electric charges between two substances. These reactions are called as electrochemical reactions. During the electrochemical reactions, either the chemical change generates electric current or the passage of electricity triggers chemical reactions. Thus, these electrochemical reactions undergo oxidation-reduction during the conversion.

**Did you know?**
English Chemist John Daniell and Physicist Michael Faraday, both credited as founders of Electrochemistry

## 2.2 Terminology

**2.2.1 Electrical Conductance:** Electrical conductance is just the opposite of resistance, while resistance measures the opposition of the flow of electrons through it by a material. The **electrical conductance** is the measure of the property of a material by which it allows the electrons or electricity to pass through it. Substances behave differently in the presence of an electric current. All the substances do not conduct electric current.

**2.2.2 Conductors:** The substances which allow the passage of electric current are known as conductors. E.g. Metals, acids and bases. The capacity of a material to conduct current is known as conductance.

**2.2.3 Insulators**: The substances which do not allow the passage of electric current through them are known as insulators. E.g. Rubber, wood and plastic.

**Types of conductors**: The conductors are broadly classified into two types.

### 2.2.4 Metallic conductors:

These are metallic substances which allow the electricity to pass through them without undergoing any chemical change. E.g. copper, silver, etc. The flow of electric current through a metallic conductor is due to the flow of electrons in the metal atoms.

### 2.2.5 Electrolytic conductors:

- The substances which allow electricity to pass through them in their molten state or in the form of their aqueous solutions are called as electrolytic conductors. During the passage of current, they undergo chemical decomposition. The conduction through electrolytes is due to the movement of ions.
- **ELECTROLYTES**: It is a substance that produces an electrically conducting solution, when dissolved in a polar solvent, such as water. The dissolved electrolyte separates into cations and anions, which disperse uniformly through the solvent. Electrically, such a solution is neutral. E.g. Acids, bases and salts are electrolytes.

### 2.2.6 Differences between Metallic conduction and Electrolytic conduction

| S.No. | Metallic conduction | Electrolytic conduction |
|---|---|---|
| 1. | Metallic conduction is due to the movement of electrons. | Electrolytic conduction is due to the movement of ions. |
| 2. | No chemical decomposition. | It involves the decomposition of the electrolyte as result of the chemical reaction. |
| 3. | It does not involve the transfer of any matter. | It involves the transfer of matter as ions. |
| 4. | Metallic conduction decreases with an increase | Electrolytic conduction increases with an increase |

## 2.2.7 Cell terminology

| | |
|---|---|
| An electrode is a solid electric conductor that carries electric current into non-metallic solids or liquids. In an electrochemical cell, reduction and oxidation reactions take place at the electrodes simultaneously. | |
| Anode | The electrode at which oxidation reaction takes place is called the anode. |
| Cathode | The electrode at which reduction reaction takes place is called the cathode. |
| Electrolyte | It is a water-soluble substance forming ions in solution and conducts electric current.<br>**Types of Electrolytes:**<br>· **Strong electrolytes:** The electrolytes which can dissociate completely into ions in solution are called strong electrolytes. E.g. HCl, NaOH, etc.<br>· **Weak electrolytes:** The electrolytes which ionize partially even at high dilution are called weak electrolytes. E.g. $CH_3COOH$, $NH_4OH$, etc.<br>· **Non- electrolytes:** Substances that do not ionize at any dilution are called non- electrolytes. E.g. Glucose, sugar, alcohol, etc. |
| Half-cell | It is a part of a cell containing an electrode dipped in an electrolytic solution. If oxidation occurs at the electrode, it is called oxidation half-cell; if reduction occurs at the electrode, it is called reduction half-cell. |
| Cell | It is a device consisting of two half-cells. Cell is a unit consisting of anode, cathode and electrolyte. |

### 2.3 Conductance of electrolytes:

- Conductance is a property of electrolytic solutions which indicates how well an electrolyte can conduct electricity. It is defined as the conducting power of all the ions present in the electrolytic solution. Its value is numerically equal to the reciprocal of the resistance to the flow of electricity through the solution. I.e. $C = 1/R$.

- The unit of conductance is S (Seimen) or $\Omega^{-1}$($ohm^{-1}$) or mho. The conductance of an electrolyte is directly proportional to the surface area, A, of the electrodes, and inversely proportional to the distance between the electrodes, l. I.e. $C \alpha A/L$ ; $C = K A/L$ , where K is called specific conductance (or conductivity).

### 2.3.1 Types of cells:

- A cell is a device consisting of two half cells. Each half cell consists of an electrode dipped in an electrolytic solution. The two types of cells are,

**1. Electrolytic cells**

**2. Electrochemical cells (or) voltaic cells (or) galvanic cells**

**2.3.1.1 Electrolytic cell:** It is a device that is used to convert electrical energy into chemical energy. In an electrolytic cell, a non-spontaneous redox reaction is made to take place through the application of electrical energy. Eg. Hydrolysis of water, electro refining, etc,.

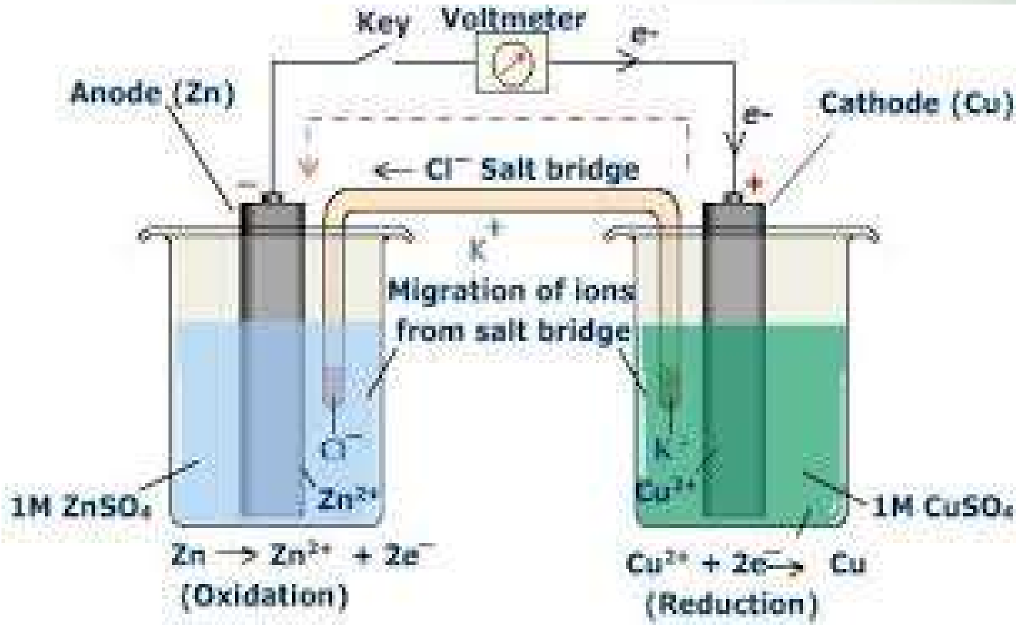
**2.3.1.2 Electrochemical cell (or) galvanic cell:**

It is a device that is used to convert chemical energy into electrical energy. Certain chemical reactions take place spontaneously and produce electricity at appropriate operating conditions.

E.g. Daniel cell, dry cell etc.

**Construction of Daniel cell:**

- It consists of a Zn electrode dipped in 1 M $ZnSO_4$ (anodic half cell) solution and a Cu electrode dipped in 1 M $CuSO_4$ (cathodic half cell) solution. Both the half-cells are connected by a salt bridge.




**Reactions occurring in the cell:**

- **At anode**: Oxidation takes place on the zinc electrode
- **At cathode**: Reduction takes place on the copper electrode

At anode – oxidation reaction (i.e) $Zn \longrightarrow Zn^{2+} + 2e^-$

At cathode – reduction reaction (i.e) $Cu^{2+} + 2e^- \longrightarrow Cu$

The net reaction is $Zn + Cu^{2+} \rightleftharpoons Zn^{2+} + Cu$

Cell is representation: $Zn_{(s)}$ / $Zn^{2+}_{(aq)}$ // $Cu^{2+}_{(aq)}$ / $Cu_{(s)}$

- The electrons released at anode flow through the external wire and are consumed by the copper ions at the cathode.

**Salt bridge:**

It consists of a U-tube containing saturated solution of KCl or $NH_4NO_3$ in agar-agar gel. It connects the two half cells of the galvanic cells. It maintains electrical neutrality within the internal circuit. If no salt bridge were present, the solution in one-half cell would accumulate a negative charge and the other half-cell would accumulate a positive charge as the reaction proceeds, quickly preventing further reaction.

### Functions of the salt bridge:

- Its main function is to prevent the potential difference that arises between the two solutions when they are in contact with each other. This potential difference is called liquid junction potential.
- It maintains electrical continuity of the solutions in the two half cells.
- It prevents the diffusion of solutions from one half cell to the other.
- It completes the electrical circuit by connecting the electrolytes in the two half cells.

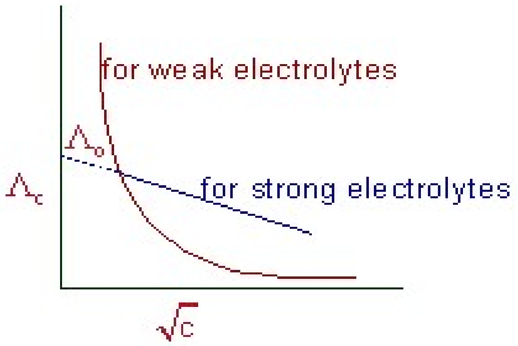
### 2.3.1.3 Differences between electrolytic cells and electrochemical cells:

| S.No. | Electrolytic cell | Electrochemical Cell |
|---|---|---|
| 1. | Electrical energy is converted into chemical energy. | Chemical energy is converted into electrical energy. |
| 2. | The anode is positive. | The anode is negative. |
| 3. | The cathode is negative. | The cathode is positive. |
| 4. | Electrons are supplied to the cell. | Electrons are drawn from the cell. |
| 5. | Rate of chemical reactions depend on the amount of electricity passed. | EMF of the cell depends on the nature of the electrodes and concentration of electrolytes. |
| 6. | Two electrodes and one electrolyte is used. | Two electrodes and two electrolytes may be used. |
| 7. | E.g. Electroplating of gold. | E.g. Daniel cell. |

## 2.4 Factors affecting conductance:

### 1. Concentration of the solution:

The conductance of electrolytes takes place due to the presence of ions in the solution. The conductivity of electrolytes increases with an increase in the concentration of ions as there will be more charge carriers (ions). If the concentration of the ions is high, the conductivity of electrolytes will also be high. The specific conductance (κ) increases with increase in concentration of solution as the number of ions per unit volume increases. Whereas, both the equivalent conductivity and molar conductance increase with **decrease** in concentration (i.e. upon dilution). On dilution, the number of molecules is fixed but only the volume increases, because of that force of attraction between the ions decreases and they flow easily and conductance increases




where ,
($\Lambda_c$) = equivalent conductivity at given concentration
(c ) = concentration
($\Lambda_o$) = equivalent conductivity at infinite dilution

### 2. Nature of the electrolyte:

The strong electrolytes ionize completely in the solution, while a weak electrolyte does not. An example of a strong electrolyte is $KNO_3$, as it has a high concentration of ions and therefore higher dissociation. An example of a weak electrolyte is $CH_3COOH$, which has a lesser number of ions and therefore lesser dissociation and lower conductance.

### 3. Temperature:

The higher temperature is considered more suitable for this process, as it improves the solubility of the electrolyte, which thereby increases the concentration of ions and electrolytic conduction.

### 4. Size of the ions:

Another factor that affects electrolytic conductance is the size of the ion. There is an inverse relationship observed, which means, the larger the size of ion, the lesser the conductance.

### 5. Nature of the solvent:

If the nature of the solvent has greater polarity, ions are solvated easily. Thus shows higher conductance. In non polar solvent conductance is poor.

### 6. Viscosity of the solvent:

When the viscosity of the solvent is high then the conductance is reduced due to hindrance in mobility of ions. An inversely proportional relationship has been observed for viscosity and electrolytic conduction.

## 2.5 Origin of Electrode potential:

- When a metal is placed in a solution of its own salt, either of the following reactions takes place.
- Positive metallic ions (from the metal) pass into the solution.

$$M \longrightarrow M^{n+} + ne^{-} \quad \text{(oxidation)}$$

(or)

Positive ions (from the solution) deposits on the metal electrode.

$$M^{n+} + ne^{-} \longrightarrow M \text{ (reduction)}$$

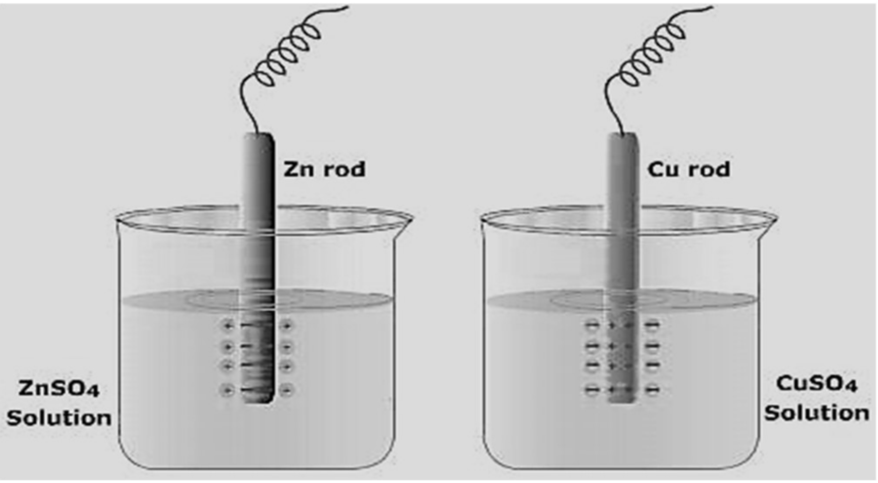
**Example 1 - Zn electrode in $ZnSO_4$ solution:**

- When Zn electrode is dipped in $ZnSO_4$ solution, Zn goes into the solution as $Zn^{2+}$ ions. Now, the Zn electrode attains a negative charge, which attracts the positive ions from the solution.

**Example 2 - Cu electrode in $CuSO_4$ solution:**

- When Cu electrode is dipped in $CuSO_4$ solution, $Cu^{2+}$ ions from the solution deposit over the metal. Now, the Cu electrode attains a positive charge, which attracts the negative ions from the solution.

**Diagram:**



- Thus, a sort of double layer (positive (or) negative ions) is formed all around the metal. This layer is called **Helmholtz electrical double layer**. A difference of potential is then set up between the metal and the solution. At equilibrium, the potential becomes a constant value, which is known as the electrode potential of metal.

### 2.5.1 Electrode potential (E) and Standard electrode potential ($E^o$):

- **Electrode potential (E)** of a metal is a measure of the tendency of a metallic electrode to lose or gain electrons when it is in contact with a solution of its own salt solution.
- The **Standard electrode potential ($E^o$)** of a metal is a measure of tendency of a metallic electrode to lose or gain electrons, when it is in contact with a solution of its own salt solution of unit molar concentration at $25^oC$.

### 2.5.2 Oxidation and Reduction potential:

- The tendency of an electrode to lose electrons is called **oxidation potential**. Similarly, the tendency of an electrode to gain electrons is known as **reduction potential.**

### 2.5.3 Factors affecting electrode potential:

- Nature of the electrode (metal)
- Concentration of metal ions in solution
- Temperature of the solution
- pH of the solution

## 2.6 Measurement of single electrode potential:

It is impossible to know the absolute value of a single electrode potential. But the difference in potential between two electrodes can be measured potentiometrically. For this purpose, a reference electrode is used. Standard hydrogen electrode (SHE) is the commonly used reference electrode, whose potential has been arbitrarily fixed as zero. In some cases, saturated calomel electrode (SCE) is also used as a reference electrode.

### 2.6.1 Over voltage

Over voltage can be defined as the difference between the potential of the electrode when gas evolution is actually observed and the theoretical reversible potential of the involved galvanic cell.

(or)

Over voltage is defined as the excess voltage that has to be applied above the theoretical decomposition potential to start the electrolysis.

**Factors affecting over voltage:**

**1. Current density:**

It is found that the over voltage depends upon current density. As the current density increases over voltage increases. (Ohms law V=IR).

**2. The surface area of the electrodes:**

As effective surface area of the electrodes increases, current density decreases, So, over voltage also decreases.

**3. Nature of the surface of the electrode:**

On smooth and polished surface, the over voltage is greater than on the rough and non polished surface, the over voltage is greater than on the rough and non polished surface.

For example, the hydrogen over voltage on rough and non polished surface is 0.005 Volts, while that on smooth surface is 0.009 Volts for same solution.

### 4. Pressure:

It is practically observed that at higher pressure over voltage slightly decreases and at low pressure it increases rapidly.

### 5. Temperature:

As the over voltage is  slow process of discharge of H+ ions. If the temperature is high, the process is fast and so the over voltage decreases. It is found that over voltage decreases by 2 mv for $1^{o}C$ rise of temperature.

### 6. PH of the solution:

In strongly acidic or alkaline solution, there is large concentration of H+ ions and OH- ions in the vicinity of the electrode, due to the large concentration , the deviation occurs.

### 7. Nature of substance deposited:

In general, metals have low overvoltage than that of hydrogen. This is because evolution of hydrogen takes place in three stages.

In general, metals have low overvoltage than that of hydrogen. This is because evolution of hydrogen takes place in three stages;

$$H_3O^+ \longrightarrow H^+ + H_2O$$

$$H^+ + e^- \longrightarrow H$$

$$H + H \longrightarrow H_2(g)$$

while that of a metal in one stage only.

$$Mn^+ + ne^- \longrightarrow M$$

## 2.6.2 Reference electrode:

- A reference electrode is an electrode which has a stable and well-known electrode potential. The high stability of the electrode potential is usually reached by employing a redox system with constant (buffered or saturated) concentrations of each participant of the redox reaction.

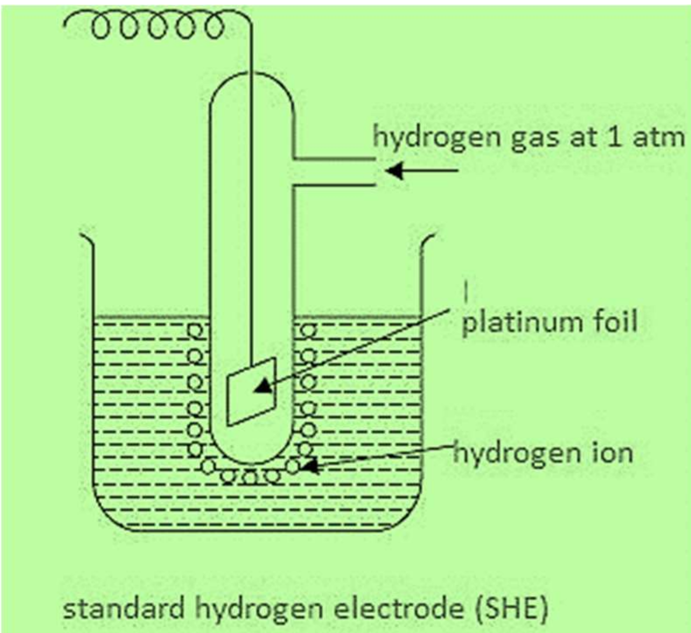
- There are many ways reference electrodes are used. The simplest one is when the reference electrode is used as a half - cell to build an electrochemical cell. This allows the potential of the other half cell to be determined. An accurate and practical method to measure an electrode's potential in isolation (absolute electrode potential) is yet to be developed.

## 2.6.2.1 Standard Hydrogen Electrode (SHE):

It is a primary reference electrode. It consists of a Pt foil connected with a Pt wire immersed in 1 M solution of $H^+$ ions at 25$^oC$. $H_2$ gas (at 1 atm) is passed through the side arm of the glass tube. Its electrode potential has been arbitrarily fixed as zero at 298K. This half cell can be combined with the another half cell, whose electrode potential need to be predicted.

- If standard hydrogen electrode acts as an anode, then the reaction is:

$$H_2 \rightarrow 2H^+ + 2e^- \qquad \text{(Oxidation)}$$



- If standard hydrogen electrode acts as cathode, then the reaction is:

**(**Reduction**)**

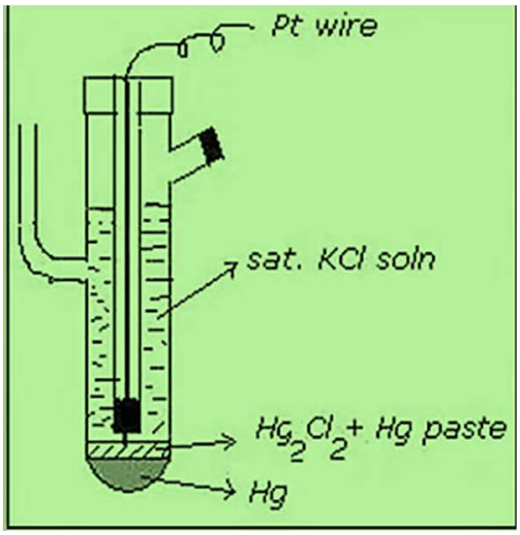
**Disadvantages:** $2H^{+} + 2e^{-} \rightarrow H_2$

- It is very difficult to maintain unit activity of $H^+$ ions.
- Difficult to maintain 1 atm pressure of hydrogen gas uniformly.
- The solution may poison the surface of the platinum electrode.
- It is difficult to get pure, dry hydrogen gas and prepare an ideal platinized platinum plate.

**2.6.2.2 Calomel electrode:**

- It is a commonly used secondary reference electrode. It consists of a glass tube, that contains mercury at the bottom covered with semi solid paste of $Hg_2Cl_2$ and above this, the tube is filled with known concentration (1M,0.1M, saturated) of KCl solution.

  A Platinum wire is in touch with mercury and it is used for electrical contact. The KCl solution inside the tube can have ionic contact with the solution outside and acts as a salt bridge. The electrode potential of the saturated calomel electrode is +0.2422V.



- When it acts as an anode :

$$2\,Hg_{(l)} + 2Cl^{-}_{(aq)} \longrightarrow Hg_2Cl_{2\,(S)} + 2e^{-} \quad \text{(Oxidation)}$$

The chloride ion from KCl solution is consumed

- When it acts as an cathode:

$$Hg_2Cl_{2\,(S)} + 2e^{-} \longrightarrow Hg_{(l)} + 2Cl^{-}_{(aq)} \quad \text{(Reduction)}$$

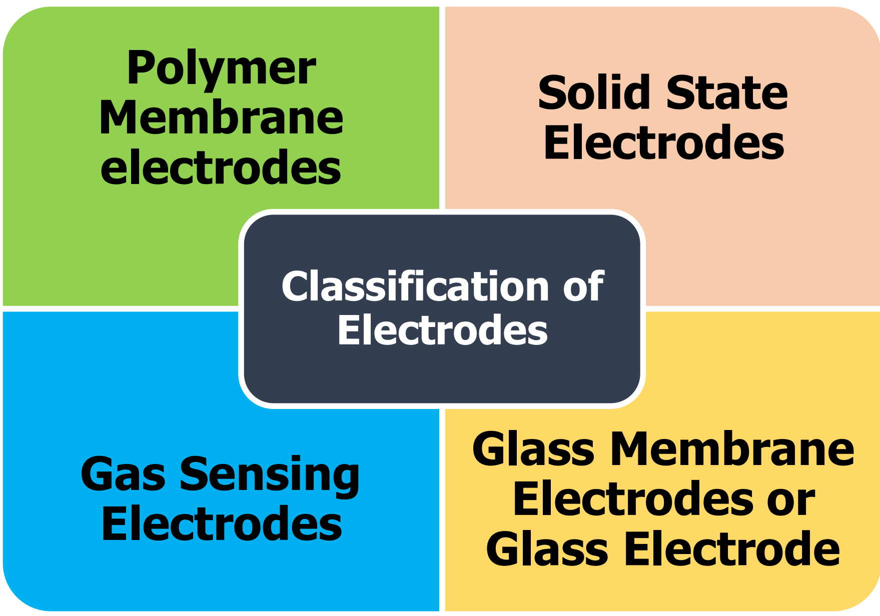
The chloride ions are released to KCl solution

- Cell representation: Pt, $Hg_{(l)}$/ $Hg_2Cl_{2\,(S)}$/ KCl (aq)

### 2.6.3 Ion-Selective Electrode

- Ion Selective Electrodes (ISE) are membrane electrodes that respond selectively to certain ions in the presence of other ions.
- The potential developed at the membrane surface is related to the concentration of the species of interest.
- The sensing part of the electrode is as an ion-specific membrane which are permeable to specific ion and also known as a specific ion electrode (SIE).

Depending upon the nature of membranes used



## Classification:

**Polymer Membrane electrodes:** Consist of various ion exchange materials in an inert matrix such as PVC, polyethylene or silicone rubber. Electrodes of this type include Potassium, Calcium and Nitrate.

**Solid State Electrodes:** It utilize relatively insoluble inorganic salts in a membrane. Potentials are developed at the membrane surface due to the ion exchange process. Examples of this type of electrode include silver / sulfide, chloride and fluoride.

**Gas Sensing Electrodes:** Gas sensing electrodes are available for the measurement of ammonia, carbon dioxide, and nitrogen oxide. This type of electrode has a gas permeable membrane and an internal buffer solution. The pH of the buffer solution changes as the gas reacts with it. The change is detected by a combination pH sensor within the housing.

**Glass Membrane Electrodes or Glass Electrode:** Glass membrane electrodes are formed by the doping of the silicon dioxide glass matrix with various chemicals. The most common of the electrode of this type is the pH electrode. Glass membrane electrodes are also used for sodium ions.

**Advantages of ion selective electrode:**

- The cost of initial setup to make analysis is relatively low.
- ISE determinations are not subject to interferences such as color in the sample

## Glass membrane electrodes : Measurement of pH

•Glass membrane is the most essential component which is sensitive and permits the passage of hydrogen ions, but no other ionic species.

•When the electrode is immersed in a test solution containing hydrogen ions the external ions diffuse through the membrane until an equilibrium is reached between the external and internal concentrations

•Thus there is a build up of charge on the inside of the membrane which is proportional to the number of hydrogen ions in the external solution.

• The glass membrane functions as an ion exchange resin, and an equilibrium set up between Na+ ions of the glass and H + ions in the solution.

• The potential difference developed across the membrane is directly proportional to the Logarithm of the ionic concentration in the external solution.

$$E_G = E^0_G - 0.0592 \text{ V pH}$$

**Construction and Working:**

● Glass Electrodes are available as half-cells which employs mono electrode.

Mono electrodes:

● It requires the use of an additional reference electrode.

● If the membrane is attached to the end of a tube that contains an internal reference electrode like Ag/AgCl, the glass electrode acts as a internal reference electrode.

$$\text{Ag} \mid \text{AgCl (s), HCl (0.1M)} \mid \text{Glass} \mid \text{test solution}^+$$

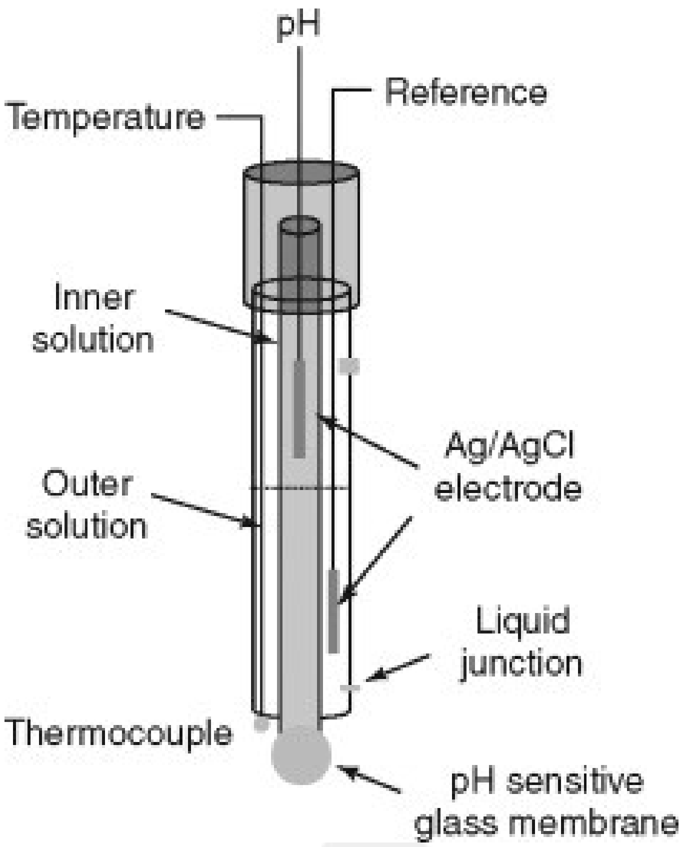
Silver or silver chloride electrode or calomel electrode is used as the second electrode. Since the potentials of the two reference electrodes are constant, any change in cell potential is due to change in potential across the membrane.

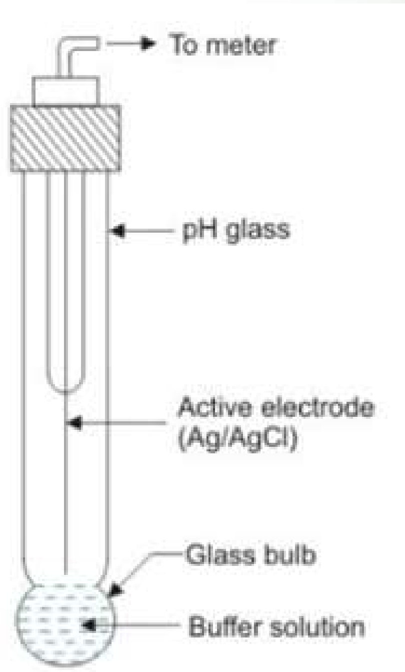
**Cell configuration:**

$$\text{Pt}|\text{Hg}|\text{Hg}_2\text{Cl}_2\text{, KCl (sat)}||\text{test solution}^+ |\text{Glass}| \text{ HCl (0.1M)}|\text{AgCl (s)} |\text{Ag}$$

$$E_{cell} = E_{left} - E_{right}$$

$$pH = E_{cell} + E^0_G - E_{ref} / 0.0592$$




**Advantages of glass electrode:**

- It is simple and can be easily used.
- Equilibrium is rapidly achieved.
- The results are accurate.
- It is not easily poisoned.

**Limitations:**

- Generally for the measurement of pH 0-10. Special glass membranes can be used for measurement up to a pH of 12. Above pH 12, cations of solutions affect the glass interface.
- Resistance of glass membrane is extremely high- special electronic potentiometers are used to measure the potential of the glass electrode.

## 2.7 Nernst equation for electrode potential:

Consider the redox equation

$$M^{n+}_{(aq)} + ne^- \rightleftharpoons M_s$$

For such a redox reversible reaction, the free energy change (ΔG) and its equilibrium constant (K) are related as

$$\Delta G = -RT\ln K + RT\ln\frac{[\text{Product}]}{[\text{Reactant}]} \qquad (1)$$

But for unit molar concentration and at 25°C,

Equation (1) becomes $\Delta G = \Delta G^0 = -RT\ln K$

$$\Delta G = \Delta G^0 + RT\ln\frac{[\text{Product}]}{[\text{Reactant}]} \qquad (2)$$

Where ΔG° = standard free energy change

The above equation (2) is known as Van't Hoff isotherm.

In any reversible reaction, decrease in free energy (-ΔG) appears as electrical energy.

Equation (2) becomes $-\Delta G = +nFE\ ;\ -\Delta G^0 = nFE^0$

$$-nFE = -nFE^0 + RT\ln\frac{[\text{Product}]}{[\text{Reactant}]} \qquad (3)$$

Where [M] = 1, $$-nFE = -nFE^0 - RT\ln[M^{n+}] \qquad (4)$$

Divide equation (4) by –nF, then equation (4) becomes

$$E = E^0 + \frac{2.303RT}{nF}\log[M^{n+}] \qquad (5)$$

When R=8.314 J/K/ mole, T=25°C (298 K), F = 96,500 coulombs, then the equation (5) becomes

$$E = E^0 + \frac{0.0591}{n} log[M^{n+}] \qquad (6)$$

In general, for reduction potential,

$$\boxed{E_{red} = E^0_{red} + \frac{0.0591}{n} log[M^{n+}] \qquad (7)}$$

And for oxidation potential,

$$\boxed{E_{ox_i} = E^0_{oxi} - \frac{0.0591}{n} log[M^{n+}] \qquad (8)}$$

Equation (7) and (8) are known as Nernst equation

## 2.7.1 Nernst equation for cell

E.g. Daniel cell is represented as

$Zn_{(s)}$ / $Zn^{2+}{}_{(aq)}$ // $Cu^{2+}{}_{(aq)}$ / $Cu_{(s)}$

$Zn \longrightarrow Zn^{2+} + 2e^-$ Oxidation half-cell reaction

$Cu^{2+} + 2e^- \longrightarrow Cu$ Reduction half-cell reaction

$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$ Net Cell reaction

$$E^0_{cell} = E^0_R - E^0_L$$

$$= \left[E^0_{Cu} + \frac{0.0591RT}{n} \log Cu^{2+}\right] - \left[E^0_{Zn} + \frac{0.0591}{n} \log Zn^{2+}\right]$$

$$= \left[E^0_{Cu} - E^0_{Zn}\right] + \frac{0.0591}{n} \log \frac{[Cu^{2+}]}{[Zn^{2+}]}$$

$$E_{cell} = E^0_{cell} + \frac{0.0591}{n} \log \frac{[Cu^{2+}]}{[Zn^{2+}]}$$

(OR)

$$= E^0_{cell} + \frac{0.0591}{n} \log \frac{[\text{Cathodic solution}]}{[\text{Anodic solution}]}$$

### 2.7.2 Applications of Nernst equation:

- To calculate the electrode potential of unknown metal.
- To study the corrosion tendency of metals.
- In applications of emf series.
- To calculate the concentration of the solution in galvanic cell.
- To calculate the emf of the cell.

### 2.7.3 Problems based on Nernst equation

**Oxidation Potential:**

1. Calculate the standard oxidation potential of zinc electrode dipped in 0.1 M $ZnSO_4$ at 25°C. $E^0_{Zn/Zn^{2+}} = 0.76$

Given : $[ZnSO_4] = [Zn^{2+}] = 0.1$ M

$E^0_{Zn/Zn^{2+}}$ = oxidation potential = 0.76 V

n = 2

The Nernst equation for oxidation potential is

$$E_{oxid} = E^0_{oxid} - \frac{0.0591}{n}\log\left[Zn^{2+}\right]$$

$$= 0.76 - \frac{0.0591}{2}\log(0.1)$$

= 0.78955 V

**Reduction Potential:**

1. Calculate the reduction potential of $Cu^{2+}$ (0.5M) / Cu at 25°C. $E^o_{(Cu^{2+}/Cu)} = 0.337\,V$

Given : $[Cu^{2+}] = 0.5$ M

$E^0_{Cu^{2+}/Cu} = 0.337\ V$

n = 2

The Nernst equation for reduction potential is

$$E_{red} = E^0_{red} + \frac{0.0591}{n}\log\left[Cu^{2+}\right]$$

$$= 0.337 + \frac{0.0591}{2}\log(0.5)$$

= 0.337 – 0.0089 V = 0.3281 V

## 2.8 Electrochemical series and its significances:

The standard electrode potential (reduction) of a number of electrodes in salt solutions are given in table. These values are determined potentiometrically by combining the electrodes with the standard electrode, whose electrode potential is zero.

### 2.8.1 Definition:

- The arrangement of various electrodes in the increasing order of their standard reduction potential (using SHE as reference electrode) is known as emf (or) electrochemical series.

The series of few elements are given in the table:

**ELECTROCHEMICAL SERIES**

| | Electrode Reaction | | E°/V | |
|---|---|---|---|---|
| ↑↑↑↑ Stronger Reducing agent | $Li^{+1} + e^-$ | → | Li -3.045 | ↓ ↓ ↓ Weaker Oxidising agent |
| | $K^+ + e^-$ | → | K -2.925 | |
| | $Na^+ + e^-$ | → | Na -2.714 | |
| | $Mg^{2+} + 2e^-$ | → | Mg -2.37 | |
| | $H_2 + 2e^-$ | → | $2H^-$ -2.25 | |
| | $Al^{3+} + 3e^-$ | → | Al -1.66 | |
| | $Zn^{2+} + 2e^-$ | → | Zn -0.76 | |
| | $Fe^{2+} + 2e^-$ | → | Fe -0.44 | |
| | $Cr^{3+} + e^-$ | → | $Cr^{2+}$ -0.41 | |
| | $Cd^{2+} + 2e^-$ | → | Cd -0.40 | |
| | $Co^{2+} + 2e^-$ | → | Co -0.277 | |
| | $Sn^{2+} + 2e^-$ | → | Sn -0.136 | |
| | $Pb^{2+} + 2e^-$ | → | Pb -0.126 | |
| | $Fe^{3+} + 2e^-$ | → | Fe -0.036 | |
| | $2H^+ + 2e^-$ | → | $H_2$ 0.000 | |
| | $Cu^{2+} + e^-$ | → | $Cu^+$ 0.153 | |
| Weaker Reducing Agent →→ | $Sn^{4+} + 2e^-$ | → | $Sn^{2+}$ 0.15 | Stronger Oxidizing agent |
| | $Cu^{2+} + 2e^-$ | → | Cu 0.337 | |
| | $Cu^+ + e^-$ | → | Cu 0.521 | |
| | $Fe^{3+} + e^-$ | → | $Fe^{2+}$ 0.771 | |
| | $\frac{1}{2} Hg_2{}^{2+} + e^-$ | → | Hg 0.789 | |
| | $Ag^+ + e^-$ | → | Ag 0.799 | |
| | $Br_2(l) + 2e^-$ | → | $2Br^-$ 1.0562 | |
| | $\frac{1}{2} Cl_2 + e^-$ | → | $Cl^-$ 1.3595 | |
| | $Au^{3+} + 3e^-$ | → | Au 1.455 | |
| | $Co^{3+} + e^-$ | → | $Co^{2+}$ 1.82 | |
| | $F_2 + 2e^-$ | → | $2F^-$ 2.87 | |

## 2.8.2 Applications of emf series (or) significances of electrochemical series:

**1. Standard EMF of a cell (E°):**

The standard emf of a cell can be calculated, if the standard electrode potential values are known using the following relation.

$$E^{o}_{cell} = E^{o}_{R} - E^{o}_{L}$$

**2. Relative ease of oxidation (or) reduction:**

- Metals at the top of the series undergo easy oxidation; metals at the bottom of the series undergo easy reduction.
- a. The fluorine has (+2.87 V) higher positive value standard reduction potential and shows higher tendency towards reduction.
- b. The lithium has (-3.01 V) higher tendency towards oxidation.

**3. Anodic (or) cathodic behavior of metal:**

- Metals lying higher in the series are anodic (more prone to corrosion) and metals lying lower in the series are cathodic (noble metals).

**4. Hydrogen displacement behavior:**

- Metals with negative reduction potential will displace $H_2$ from an acid solution. E.g. ($E^{o}_{Zn}$ = -0.76 V)

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2 \uparrow$$

- Metal with positive reduction potential will not displace the $H_2$ from an acid solution. ($E^{o}_{Ag}$ = +0.80 V)

$$Ag + H_2SO_4 \rightarrow No\ reaction$$

**5. Replacement tendency of one element by another:**

- The metals that have a higher position in emf series can displace the metals which have a lower position in the emf series from their solution.

  E.g. $Zn(s) + CuSO_4 \longrightarrow ZnSO_4 + Cu\ (s)$

- Since zinc is placed above copper in emf series, zinc can replace copper from the copper solution.

**6. Predicting the spontaneity (or) feasibility of a redox reaction:**

- If the net emf $E^o$ of the cell is positive, the reaction is feasible (or) spontaneous **($\Delta G^o$ = -ve)**. But if the net $E^o$ of the cell is negative, the reaction is not feasible (or) non spontaneous **($\Delta G^o$ = +ve)**.

  E.g. For Daniel cell

$$E^o_{cell} = E^o_R - E^o_L$$
$$= 0.34 - (-0.76)$$
$$= +1.1V$$

Therefore the reaction is feasible.

**7. Determination of standard free energy ($\Delta G^o$) and equilibrium constant for the reaction:**

- EMF series is used to determine the standard free energy change ($\Delta G^o$) and equilibrium constant (K) for the reaction. We know that, from the value of $E^o$, the equilibrium constant for the cell reaction can be calculated.

$$-\Delta G^\circ = nFE^0 = 2.303RT\log K$$

$$\therefore \log K = \frac{-\Delta G^o}{2.303RT} = \frac{nFE^\circ}{2.303RT}$$

## 2.9 Chemical Sensor:

Chemical sensors are measurement devices, that convert a chemical or physical property of a specific analyte into a measurable signal, whose magnitude is normally proportional to the concentration of the analyte. Chemical sensors are used in numerous applications, such as medical, automotive, nanotechnology and home detection systems.

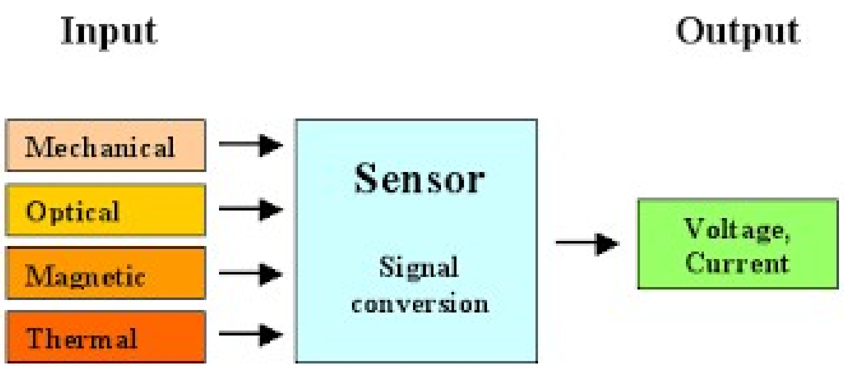
https://slideplayer.com/slide/5762873/

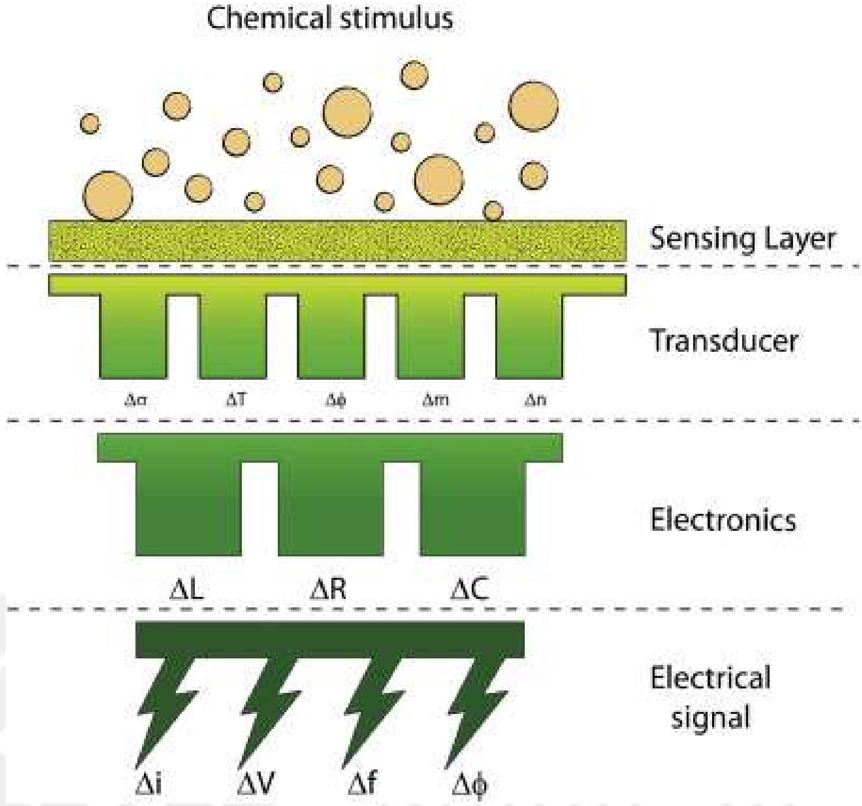
### 2.9.1 Principle of chemical sensors:

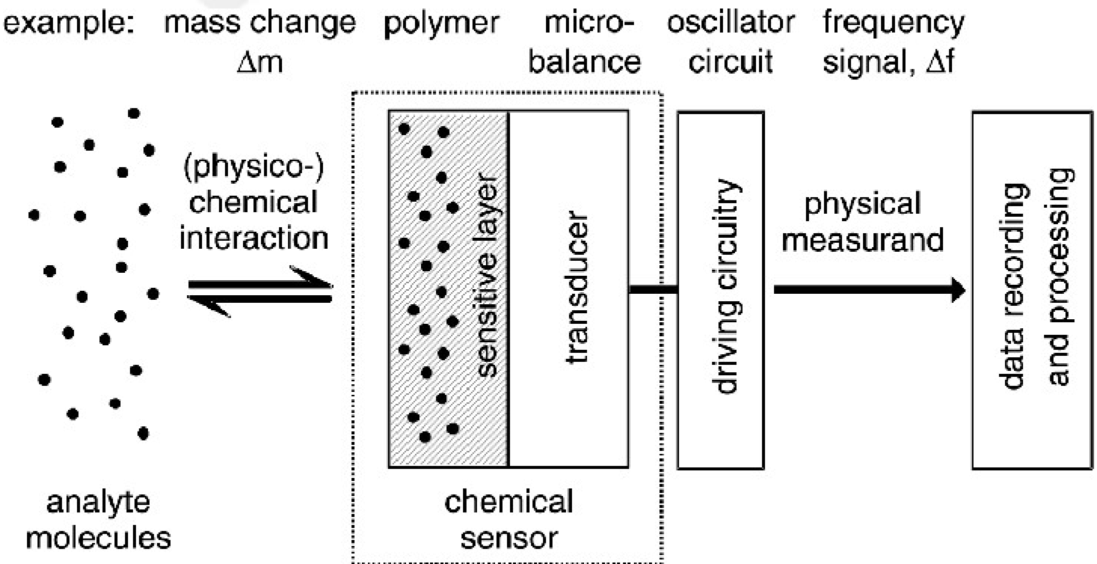
The chemical sensor is an analyzer that responds to a particular analyte in a selective and reversible way and transforms input chemical quantity, ranging from the concentration of a specific sample component to a total composition analysis, into an analytically electrical signal.

**Characteristics of chemical sensors are as follows**

- It should be in direct contact with the investigated subject,
- Transform non-electric information into electric signals,
- Respond quickly,
- Operate continuously or at least in repeated cycles,
- Compact and cheap
- They should transform chemical quantities into electrical signals
- Be specific, (i.e. they should respond exclusively to one analyte, or at least be selective to a group of analytes).




Chemical stimulus
Sensing Layer
Transducer
Δσ ΔT Δϕ Δm Δn
Electronics
ΔL ΔR ΔC
Electrical signal
Δi ΔV Δf Δϕ


example: mass change Δm polymer micro-balance oscillator circuit frequency signal, Δf
(physico-) chemical interaction
sensitive layer
transducer
driving circuitry
physical measurand
data recording and processing
analyte molecules
chemical sensor

## 2.9.2 Basic components of chemical sensors:

Most of the sensor will possess the following two basic components:

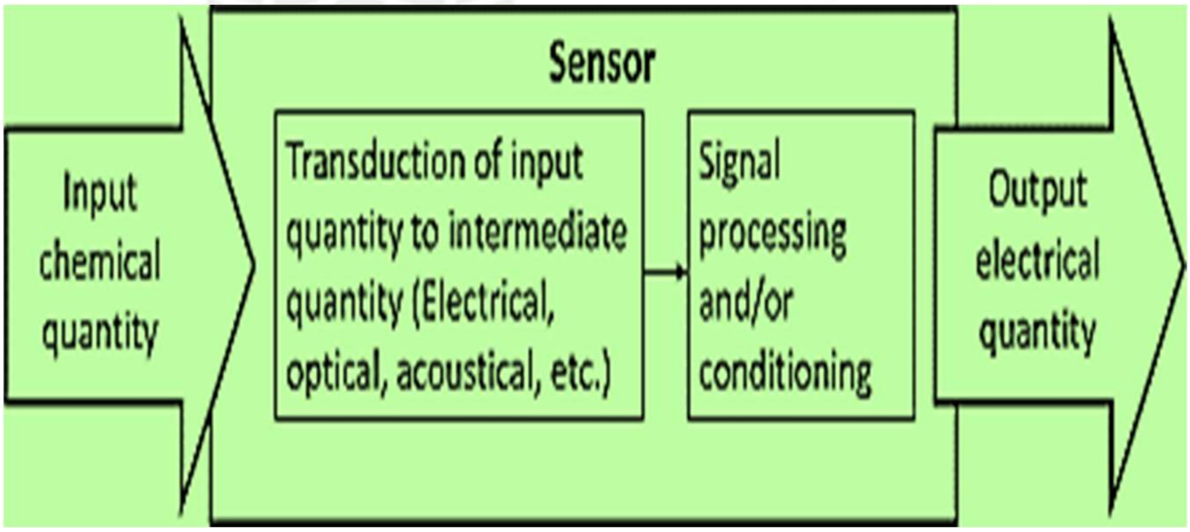
- **Receptors**
- **Transducers.**

**Receptors**

The **receptor** is the component of the chemical sensor that comes into physical contact with the analyte. Depending on the sensor, the receptor interacts with the analyte in distinct ways. Sensors trigger the chemical reactions with the analyte.

**Transducers**

Transducers are responsible for in taking the chemical information of the interaction between the receptor and analyte and converting it into corresponding electrical information.



## 2.9.3 Based on the working principle, the chemical sensor can be classified into:

- Optical sensors
- Electrochemical sensors
- Mass sensors
- Magnetic sensors
- Thermal sensors

**Optical sensors:** An optical sensor converts light rays into electronic signals. It measures the physical quantity of light and then translates it into a form that is readable by an instrument.

**Electrochemical sensor:** It utilizes the electrochemical effect between the analyte and the electrodes present. It helps in measuring the concentration of a specific gas with an external circuit. It is based on redox reactions.

**Mass sensors:** A mass airflow sensor (MAS) determines the mass of air entering a vehicle's fuel injection engine, and passes that data to the Engine Control Unit, or ECU. The air mass information is necessary for the ECU to correctly balance and deliver the correct amount of fuel to the engine. It helps to keep the air/fuel ratio at the optimal level.

**Magnetic sensors:** The simplest magnetic sensor consists of a wire coiled around a permanent magnet. A ferrous object approaching the sensor changes the magnetic flux and generates a voltage at the coil terminals. It helps in security and military applications such as detection, discrimination and localization of ferromagnetic and conducting objects.

**Thermal sensors**: A temperature sensor is an electronic device that measures the temperature of its environment and converts the input data into electronic data to record, monitor or signal temperature changes. Such sensors are often used in hazardous environments like nuclear power plants or thermal power plants or else in the determination of heat of hydration in mass concrete structures.

Sensors can be further classified into various types based on the type of sensing objects.

## 2.10 Breath analyzer:

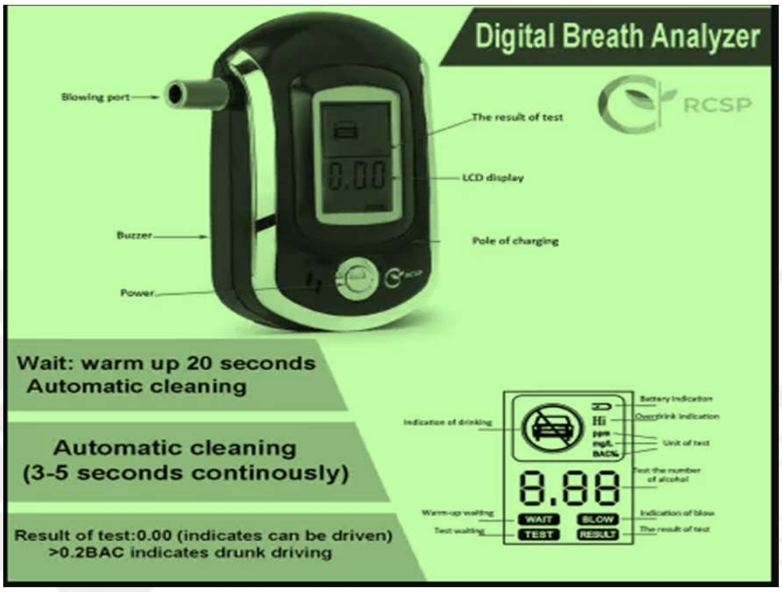
**Breath analyzer**, also called **Breathalyzer**, electrochemical sensor that is specifically designed to measure a person's blood alcohol content (BAC), mainly to avoid accidents while driving the vehicles. Breath analyzer was developed by Rolla N Harger, which was called as drunkometer. It was the first practical machine to test blood alcohol levels in human beings successfully. Harger set out to work on his breath analyzer in 1930 and received his patent in 1936.

- **Detection of alcohol content using Breathalyzer:**

The alcohol is not digested upon absorption, nor chemically changed in the bloodstream. As the blood goes through the lungs, some of the alcohol moves across the membranes of the lung's air sacs (alveoli) into the air, because alcohol will evaporate from a solution i.e., it is volatile. As the alcohol in the alveolar air is exhaled, it can be detected by the breath alcohol testing device.

**Breathalyzer device contains:**

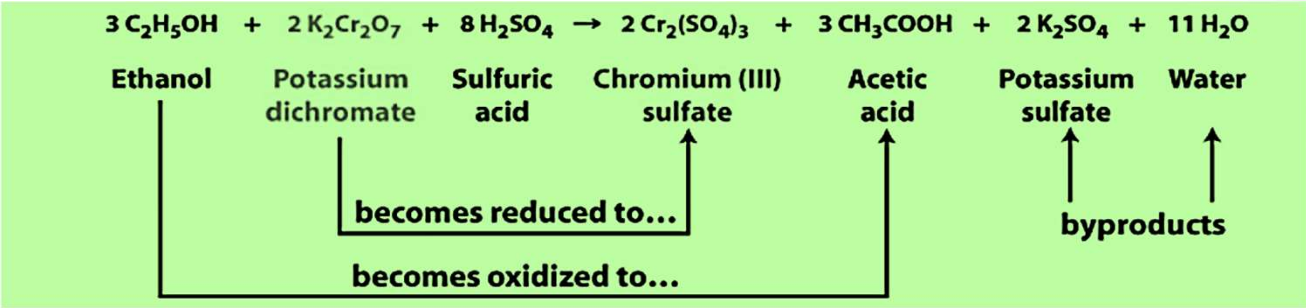
- A system to sample the breath of the suspect
- Two glass vials containing the chemical reaction mixture
- A system of photocells connected to a meter to measure the color change associated with the chemical reaction
- To measure alcohol, a suspect breathes into the device. The breath sample is bubbled in one vial through a mixture of sulfuric acid, potassium dichromate, silver nitrate and water. The principle of the measurement is based on the following chemical reaction.


**Digital Alcohol Breath Analyzer**

## Chemistry of Breathalyzer:

- The sulfuric acid removes the alcohol from the air into a liquid solution.
- The silver nitrate is used as a catalyst. The sulfuric acid, in addition to removing the alcohol from the air, it also provides the acidic condition needed for this reaction.
- The alcohol reacts with potassium dichromate and produces chromium sulfate potassium sulfate acetic acid and water




During this reaction, the reddish-orange dichromate ion changes colour to the green chromium ion, when it reacts with the alcohol. The degree of the colour change is directly related to the level of alcohol in the expelled air. To determine the amount of alcohol in that air, the reacted mixture is compared to a vial of un reacted mixture in the photocell system, which produces an electric current, that causes the needle in the meter to move from its resting place.

### 2.10.1 MODERN BREATHALYZERS

Mordern breathalyzers are

1.Electrochemical Fuel Cell Breathalysers
2. Infrared Optical Sensor Breathalysers
3. Dual Sensor Breathalysers
4. Semiconductor Breathalysers

#### 1. Electrochemical Fuel Cell Breathalysers

Electrochemical fuel cell breathalysers are devices in which an electrical current is produced as a result of a chemical reaction taking place on the surface of an electrode system. The oxidation of alcohol/ethanol to acetaldehyde is carried out in a fuel cell consisting of a deposit of gold and platinum on a porous disc. The chemical reaction that takes place converts any alcohol into acetic acid, this conversion produces a fixed number of electrons per molecule of alcohol.

The small electrical current produced by the alcohol in a persons breath reacting on the electrode within the machine can be used to give a digital display, to move a needle or to trigger certain lights on the device, depending on the amount of alcohol detected. Fuel cell technology is particularly suitable for portable screening devices, due to the small size of the cells and the low power requirements of the technology.

**Advantages:**

Sensor is highly specific and sensitive to alcohol.

The alcohol measurement cannot be influenced by endogenous substances such as acetone (produced by diabetics), Carbon Monoxide or Toluene

Long life cycle

**Disadvantages:**

It cannot detect if a breath sample was alveolar (deep lung air). As a result it may produce a falsely high reading if a subject has recently drank and still has alcohol in his mouth

**2. Infrared Optical Sensor Breathalysers**

Infrared optical sensor breathalysers use infrared spectroscopy which identifies different molecules based on the way they absorb infrared light. Molecules constantly vibrate and the vibrations change when they start to absorb infrared light. The bond present in the molecules absorb infrared light at different wave lengths. A photocell used in the machine detects adsorbed infrared light by the ethanol. The photocell then produces an electrical pulse based on the absorbed light. The electrical pulse is then sent to a microprocessor within the machine which calculates a person's BAC level based on how much light has been absorbed.

**Advantages:**

Ensures that the breath sample is alveolar (deep lung air)

Provides pinpoint accuracy and therefore used for evidential purposes in prosecutions

It is durable

### 3. Dual Sensor Breathalysers

Many evidential desktop breath testing machines use dual sensor systems. Adopts both infrared and electrochemical sensors (EC/IR). In this dual sensor, two independent measurements will be taken from the same sample of air and ensures that all readings produced are 100% accurate

### 4. Semiconductor Breathalysers

Semiconductor breathalysers measure the level of alcohol present in a breath sample based upon the change in resistance upon the semiconductors in the device. The semiconductors produce a small standing electrical current. When alcohol comes into contact with the semiconductor, it is absorbed on the surface of the semiconductor, changes the resistivity and hence changes the electrical current. This gives an indication to the amount of alcohol present in the breath sample.The surface effect by which they operate is dependent on the atmosphere. Their sensitivity to alcohol can vary depending on the climate and altitude of where the breath test is carried out.

**Advantages:**

•Small in size and cheap to manufacture and buy

•Readily available in convenience stores and mail order catalogues

**Disadvantages:**

Sensor can be unstable

Highly sensitive to the atmosphere

Carbon monoxide, cigarette smoke and many other environmental gases can effect the readings produced

Sensitive to changes in temperature, humidity and breath flow patterns

## 2.11 Gas Sensors:

➢A gas sensor is a device which detects the presence or concentration of gases in the atmosphere. Based on the concentration of the gas the sensor produces a corresponding potential difference by changing the resistance of the material inside the sensor, which can be measured as output voltage.

➢Gas sensors vary widely in size (portable and fixed), range, and sensing ability.

➢Gas sensor, as one of the most important devices to detect noxious gases, provides a vital way to monitor the concentration and environmental information of gas in order to guarantee the safety of production.

➢ Graphene, transition metal chalcogenides, boron nitride, transition metal carbides/nitrides, metal organic frameworks, and metal oxide nanosheets as 2D materials represent gas-sensing materials of the future, especially in medical devices, such as breath sensing.

The major applications of gas sensors are

- Process control industries
- Environmental monitoring
- Boiler control
- Fire detection
- Alcohol breath tests
- Detection of harmful gases
- Home safety(gas leaks, smoke and carbon monoxide)
- Grading of agro-products like coffee and spices

The four main types of gas sensors:

(i) Electrochemical sensors

(ii) Catalytic sensors

(iii) Infrared sensors

(iv) Photo-ionization sensors

The most commonly used infrared sensor is NDIR $CO_2$ which is discussed in detail.

### 2.11.1 Carbon Dioxide Sensors

- $CO_2$ sensors is an instrument that is used to detect the $CO_2$ gas content in the air or its surroundings, generates an alarm to alert the people.



**$CO_2$ Sensor**

- This type of sensor plays an essential role in making a good atmospheric situation for the public. The application areas of CO2 sensors mainly include different industries like carbonated beverage beer, coal, agricultural planting, agricultural breeding & the daily life of people.

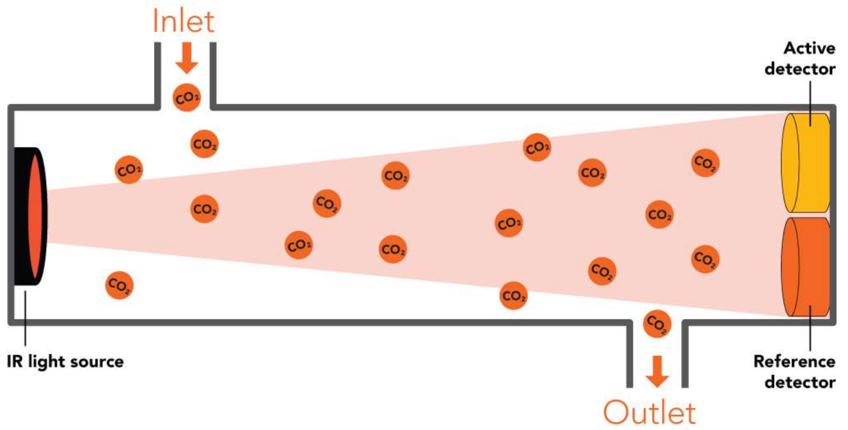
The $CO_2$ sensors are available in different types like

- **Non-dispersive( NDIR)**
- **Electrochemical**
- **Semiconductor**
- **Catalytic combustion**

Among various types, NDIR $Co_2$ sensors have high performance advantages by providing enhanced long-term stability, accuracy, and low power consumption for $CO_2$ measurement. So NDIR $CO_2$ Sensors is discussed below.

## 2.11.2 Non-Dispersive Infrared (NDIR) $CO_2$ Sensor

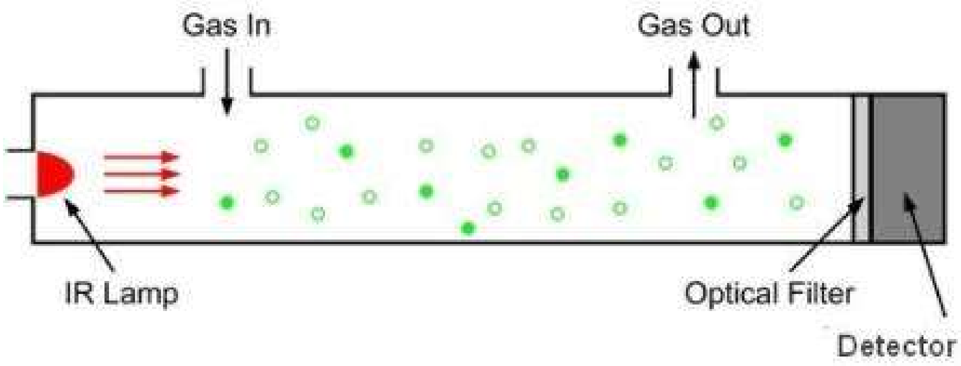
- **Non-Dispersive infrared** sensor is the most common type of sensor used to used to detect and monitor carbon dioxide, or $CO_2$ in air also known as NDIR detection.




**NDIR $CO_2$ Sensor**

**Principle:**

When infrared radiation interacts with gas molecules, infrared light is absorbed by the gas molecules at a particular wavelength, causing vibration of the gas molecules. NDIR gas sensors detect decrease in transmitted infrared light which is in proportion to gas concentration. This transmittance, the ratio of transmitted radiation energy to the incident energy, is dependent on target gas concentration




**NDIR $CO_2$ Sensor**

## Components:

**Infrared source:** (a)Infrared light emitters and (b) Infrared Light sensors

**(a) Infrared light emitters:** LED bulb is the common source of IR light emitter. It can be broadly classified into two types (i) optical type and (ii) thermal type.

- **Optical type:** directly converts current into light by using the recombination of electrons and holes in a semiconductor.
- **Thermal type:** emits light by supplying current to the heat element and consequently heating the object.

(b) **Infrared light sensors :** It is also classified into 2 types (i) optical and (ii) thermal IR Sensors

- **Optical IR sensors** (photodiode) use photovoltaic power in a semiconductor to convert light into a current.
- **Thermal IR sensor** detects a voltage (or polarization) when a temperature change occurs from a warming object. **Thermal IR sensors** include thermopile and pyroelectric sensors.

**Optical filter** : A narrow optical filter used to respond particularly $CO_2$ absorption band and eliminates every thing else.

**Detector** : Pyroelectric detector used as detector. A detector is a device that responds to a stimulus or form of energy. It then generates a signal that can be measured or interpreted

**WORKING:**

- The sensor works by an infrared (IR) lamp directing waves of light through a tube filled with a sample of air. This air moves toward an optical filter in front of an IR light detector. The IR light detector measures the amount of IR light that passes through the optical filter.
- The band of IR radiation also produced by the lamp is very close to the 4.26-micron absorption band of $CO_2$. Because the IR spectrum of $CO_2$ is unique, matching the light source wavelength serves as a signature or "fingerprint" to identify the $CO_2$ molecule.
- As the IR light passes through the length of the tube, the $CO_2$ gas molecules absorb the specific band of IR light while letting other wavelengths of light pass through. At the detector end, the remaining light hits an optical filter that absorbs every wavelength of light except the wavelength absorbed by $CO_2$ molecules in the air sample tube.

- Finally, an IR detector reads the remaining amount of light that was not absorbed by the $CO_2$ molecules or the optical filter.

**Advantage:**

The advantages of the NDIR $CO_2$ sensor mainly include fast analysis speed, High

sensitivity, long service life & good stability.

### 2.11.3 Applications:

The applications of a NDIR $CO_2$ sensor include the following.

- Indoor and outdoor air quality monitoring,
- Air purifier
- Ventilation and air conditioning
- Life-Science & Medical Industries.
- Testing of Fire Suppression.
- Aerospace Industries.
- Fuel gas emissions

$CO_2$ sensors are used for precise Carbon Dioxide measurement in different Industries.

## 2.12 Sensor for Health Care - Glucose

Glucose is a major source of energy for cellular activity in the living body. It is crucial to maintain a proper concentration of glucose in the blood, and the homeostatic system in human physiology (e.g., nerves and the endocrine system) tightly regulates the glucose level. Excess glucose in the blood plasma induces a hyperglycemic condition, which causes multiple complications such as blindness, cardiovascular disorders and kidney failure. Because of the severe medical ramifications of diabetes-associated complications, there is a critical need for personal monitoring and control of the blood glucose level. Therefore, glucose sensors have been developed to accurately estimate the concentration of blood glucose and to assist the precise delivery of the corresponding medication for homeostatic regulation. In humans, normal blood glucose levels range between **80–120** mg/dL with spikes reaching up to **250** mg/dL after meals.

There are a number of methods for glucose measurement of which **optical** and **electrochemical** analyses have been widely investigated.

- **Optical methods** use the change of colour in an indicator that reflects the concentration of glucose. The colour of the dyes changes during an enzymatic reaction that converts glucose to its metabolites. Although the colour change provides patients an intuitive way to check for the presence of blood glucose, it is neither sufficient to quantify the level of glucose nor effective for measuring low glucose levels. Even if quantitative measurements are possible, it often requires a bulky spectrophotometer, making the colorimetric method unsuitable for commercial use.
- **Electrochemical analysis** involves a simple and quantitative mode of operation and is therefore the most widely employed method in glucose sensors. Electrochemical glucose sensors can be used over a broad detection range. The electrochemical signals are measured and directly converted to the corresponding concentration of glucose.

### 2.12.1 Glucose sensors

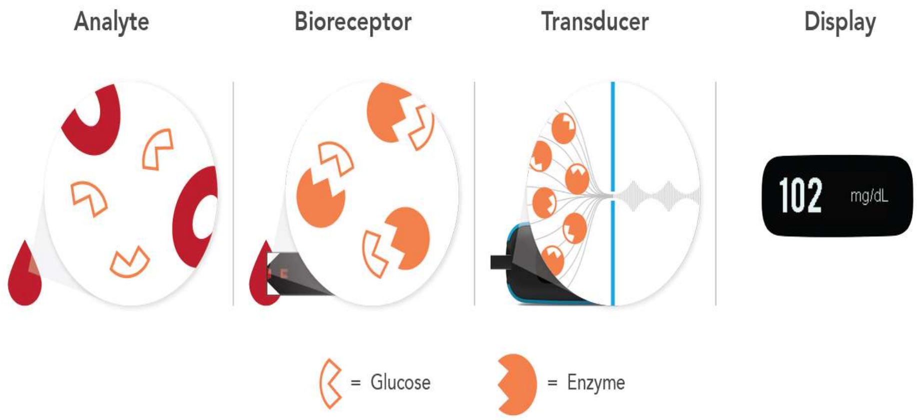
Glucose sensors are biosensors designed to detect glucose levels, which is vital to managing diabetes. A biosensor is a device that uses a living organism or biological molecules, especially enzymes or antibodies, to detect the presence of chemicals. For a glucose biosensor, the following components are used:

- **Analyte:** A substance with chemical constituents that are being identified and measured. In this instance, glucose is the analyte that the biosensor is designed to detect.

- **Bioreceptor:** This is a molecule that specifically recognizes the analyte. For the detection of glucose, specific enzymes are used, which are proteins that facilitate a chemical reaction. For example, the test strip for a blood glucose test contains the enzyme that interacts with the analyte in the drop of blood.

- **Transducer:** This part of the biosensor converts one form of energy into another. Specifically, it converts the recognition of the bioreceptor into a measurable signal. Most modern-day glucose meters and continuous glucose monitors measure electrical signals, although earlier generations of glucose meters used a colorimetric process (colour change) that was measured optically.

- **Electronics and display:** These components process the transduced signal and prepare it for display. The processed signals are then quantified and shown on either the glucose meter's display or the receiver for a continuous glucose monitor (or compatible app).



Common enzymes (bioreceptors) that are used to detect glucose include:

- Glucose oxidase (GOx)
- Glucose dehydrogenase nicotinamide adenine dinucleotide (GDH-NAD)
- Glucose dehydrogenase flavin adenine dinucleotide (GDH-FAD)
- Glucose dehydrogenase pyrroloquinoline quinone (GDH-PQQ)

**Mechanism:**

The majority of blood glucose sensors, or glucose meters, are categorized as amperometric sensors, In amperometric glucose sensors, reducing property of glucose is measured as a current. Sensors contain electrodes to measure the current generated by an enzymatic reaction usually between glucose, an enzyme, and a mediator. Use of glucose oxidase (GOx or GOD) has become the gold standard for glucose sensing. The initial concept of glucose enzyme electrodes, where a thin layer of GOx was entrapped via a semipermeable membrane, was introduced by Clark and Lyons. Sensing was based on the measurement of the oxygen consumed by the enzyme-catalyzed reaction.

$$\text{Glucose} + O_2 \xrightarrow{GO_x} \text{Gluconic acid} + H_2O_2$$

$$\text{Glucose} + GOx_{(ox)} \rightarrow \text{Gluconic acid} + GOx_{(red)}$$

$$GOX_{(red)} + 2M_{(ox)} \rightarrow GOx_{(ox)} + 2M_{(red)} + 2H^+$$

$$2M_{(red)} \rightarrow 2M_{(ox)} + 2e^-$$

In this method, glucose reacts with the enzyme GOx(ox). The reduced enzyme GOx(red) then reduces two mediator M(ox) ions to M(red), which is oxidized back to M(ox) at the electrode surface. The oxidation process $2M(red) \rightarrow 2M(ox) + 2e^{-}$ is measured as the current by the electrode. However, for this type of early glucose biosensors, a high operation potential is required to perform the amperometric measurement of hydrogen peroxide. Improved methods utilize artificial mediators instead of oxygen to transfer electrons between the GOx and the electrode . Reduced mediators are formed and reoxidized at the electrode, providing an electrical signal to be measured.

### 2.1.2 Advantages :

1. It allows patients and clinicians to detect high or low blood glucose levels.

2. It helps patients by allowing them to immediately confirm acute hypoglycemia or hyperglycemia.

3. The technology facilitates the patients about diabetes and its management by giving the patients more self-care responsibilities.

4. It also helps the people to move towards healthy behavior.


**Blood Glucose Sensor**

## Practice Quiz

- https://docs.google.com/forms/d/e/1FAIpQLSdorLY1fpinHUI5EurPrJNLcK0ZqoiMWlElB7zE_GKcC6kdMA/viewform?usp=share_link

# Assignment

## Unit II

| S.No. | Questions | K level |
|---|---|---|
| 1. | What is the potential of a lead electrode that is in contact with a solution of 0.015 M $Pb^{2+}$ ions? Standard electrode potential for Pb → $Pb^{2+}$ + 2e- is 0.13 volt. | K3 |
| 2. | Find the oxidation potential of Zn electrode that is in contact with a solution of 0.2M at 25ºC. Standard oxidation potential of $Zn/Zn^{2+}$ is 0.763V. | K3 |
| 3 | Can we store $AgNO_3$ solution in a copper vessel? | K3 |
| 4. | Determine whether the following cell reaction is feasible or not.<br>Ag // Zn [$E^0Ag$ = 0.8V, $E^0Zn$ = -0.76V] | K3 |
| 5. | Which element (Zn, Ag) will react with $H_2SO_4$ to give $H_2$? Explain. | K3 |
| 6. | Write a note on $CO_2$ breath analyzer and its applications? | K3 |
| 7. | Write short notes on Glucose sensors. | K3 |

# Part-A Question and Answer

| S.No. | PART-A<br>Q & A | K level | CO |
|---|---|---|---|
| 1 | **What is the difference between metallic and electrolytic conduction?**<br><table><tr><th>S.No.</th><th>Metallic conduction</th><th>Electrolytic conduction</th></tr><tr><td>1</td><td>It is due to the movement of electrons.</td><td>It is due to the movement of ions.</td></tr><tr><td>2</td><td>No chemical decomposition.</td><td>It involves the decomposition of the electrolyte as a result of the chemical reaction.</td></tr></table> | K2 | CO2 |
| 2 | **What are the types of electrolytes? Give examples for each type?**<br>There are three types of electrolytes. They are as follows,<br>1) Strong electrolytes :e.g→HCl,NaOH<br>2) Weak electrolytes :e.g→$CH_3COOH$,$NH_4OH$<br>3) Nonelectrolytes :e.g→ Glucose, Sugar | K1 | CO2 |
| 3 | **What is the difference between electrochemical and electrolytic cells?**<br><table><tr><td>S.No.</td><td>Electrolytic cell</td><td>Electrochemical Cell</td></tr><tr><td>1</td><td>Converts electrical energy into chemical energy.</td><td>Converts chemical energy into electrical energy.</td></tr><tr><td>2</td><td>A cathode is negative and an anode is positive.</td><td>A cathode is positive and an anode is negative.</td></tr><tr><td>3</td><td>Electrons are supplied to the cell.</td><td>Electrons are drawn from the cell</td></tr></table> | K2 | CO2 |

# Part-A Question and Answer

| S.No. | PART-A<br>Q & A | K level | CO |
|---|---|---|---|
| 4 | **What are single and Standard Electrode potentials?**<br>Electrode potential (E) of a metal is the measure of the tendency of a metallic electrode to lose or gain electrons when it is in contact with a solution of its own salt.<br>The Standard electrode potential ($E^O$) of a metal is the measure of tendency of a metallic electrode to lose or gain electrons, when it is in contact with a solution of its own salt solution of unit molar concentration at $25^OC$. | K1 | CO2 |
| 5 | **Bring out the symbolic representation of SHE. What are its disadvantages?**<br>Representation: Pt,$H_2$(1atm) / $H^+$(1M)<br>Disadvantages:<br>1.It is very difficult to maintain unit activity of $H^+$ ions.<br>2.Difficult to maintain 1 atm pressure of hydrogen gas uniformly.<br>3.The solution may poison the surface of the platinum electrode. | K1 | CO2 |
| 6 | **What is the need for secondary reference electrode?**<br>The use of SHE is difficult, because it is difficult to maintain 1M $H^+$ ion concentration and the pressure of the gas at 1 atmosphere. Hence other reference electrodes are used.<br>E.g. Saturated calomel electrode. | K2 | CO2 |

| S.No. | PART-A<br>Q & A | K level | CO |
|---|---|---|---|
| 7 | **Give the cell representation, electrode potential and reactions of a calomel electrode.**<br>Cell representation: Pt, $Hg_{(l)}$/ $Hg_2Cl_{2\,(S)}$/ $KCl_{(aq)}$<br>Electrode potential: + 0.2422V<br>If it acts as anode:<br>$2\,Hg_{(l)} + 2Cl_{(aq)} \rightarrow Hg_2Cl_{2(S)} + 2e^-$<br>If it acts as cathode:<br>$Hg_2Cl_{2\,(S)} + 2e^- \rightarrow 2\,Hg_{(l)} + 2Cl^-_{(aq)}$ | K1 | CO2 |
| 8 | **Define emf series. Identify the electrode potential of any two metals using emf series.**<br>The arrangement of various electrodes in the increasing order of their standard reduction potential is known as emf (or) electrochemical series.<br>$Zn^{2+}$ / Zn = - 0.76 V<br>$Cu^{2+}$/ Cu = + 0.34 V | K3 | CO2 |
| 9 | **Zinc displaces $H_2$ from HCl but Cu does not. Give reason?**<br>The metals that have a higher position in emf series can displace the metals which have a lower position in the emf series from their solution.<br>E.g. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$<br>Since zinc is placed above copper in emf series, zinc can replace copper from the copper solution. | K3 | CO2 |
| 10 | **How will you predict the spontaneity of a reaction using emf series?**<br>If EMF of the cell is positive, the reaction is feasible (or) spontaneous ($\Delta G$ = -ve).<br>But EMF of the cell is negative, the reaction is not feasible (or) non spontaneous ($\Delta G$ = +ve). | K2 | CO2 |

| S.No. | PART-A<br>Q & A | K level | CO |
|---|---|---|---|
| 11 | **Define Oxidation and Reduction potential?**<br>The tendency of an electrode to lose electrons is called oxidation potential.<br>The tendency of an electrode to gain electrons is known as reduction potential. | K1 | CO2 |
| 12 | **What is Nernst equation? Discuss the terms involved.**<br>The Nernst equation is expressed as,<br>$E = E^o + 2.303(RT/nF) \log[M^{n+}]$<br>where<br>E - measured potential of the electrode<br>$E^\circ$- standard electrode potential for the ion<br>T - absolute temperature<br>n - number of electrons involved<br>C - concentration of the ion<br>R - gas constant<br>F - Faraday constant | K1 | CO2 |
| 13 | **Mention the applications of Nernst equation.**<br>1.To calculate the electrode potential of unknown metal.<br>2. To study the corrosion tendency of metals.<br>3. Used in applications of emf series.<br>4. To calculate concentration of the solution in a galvanic cell.<br>5. To calculate the emf of a cell. | K2 | CO2 |

| S.No. | PART-A<br>Q & A | K level | CO |
|---|---|---|---|
| 14 | **Calculate the reduction potential of $Cu^{2+}$ / Cu = 0.5M at 25°C. ($E^o_{Cu2+ / Cu}$ = 0.337V)**<br>Given: Concentration of $[Cu^{2+}]$=0.5M, $E^o_{Cu^{2+}/Cu}$ = 0.337V<br>The Nernst equation for reduction potential is<br>$E = E^o + (0.0591/n) \log[Cu^{2+}]$<br>$= 0.337 + (0.0591/2) \log[0.5]$<br>$= 0.337 + 0.02955 (-0.3010)$<br>$= 0.337 - 0.0089$<br>$= 0.328V$ | | |
| 15 | **Find the oxidation potential of $Zn/Zn^{2+}$ = 0.2M, at 25°C. Standard oxidation potential of $Zn/Zn^{2+}$ = 0.763V**<br>The Nernst equation for oxidation potential is<br>$E = E^o - (0.0591/n) \log[Zn^{2+}]$<br>$= 0.763 - (0.0591/2) \log[0.2]$<br>$= 0.763 - 0.02955(-0.69897)$<br>$= 0.763 + 0.02065$<br>$= 0.78365V$ | K3 | CO2 |
| 16 | **Define chemical sensor**<br>A chemical sensor is a device, that measures and detects chemical qualities in an analyte and converts the sensed chemical data into electronic data. | K2 | CO2 |
| 17 | **What do you mean by Breath analyzer?**<br>A breathalyzer is an electrochemical sensor that is specifically designed to measure a person's blood alcohol content (BAC), mainly to avoid accidents, while driving the vehicles. | K2 | CO2 |

| | | | |
|---|---|---|---|
| 18 | **What is Carbon Dioxide Sensor and give its types?**<br>CO2 sensors is an instrument that is used to detect the CO2 gas content in the air or its surroundings, generates an alarm to alert the people.<br>The $CO_2$ sensors are available in different types like<br>•**Non-dispersive( NDIR)**<br>•**Electrochemical**<br>•**Semiconductor**<br>•**Catalytic combustion** | K2 | CO2 |
| 19 | **Define Gas sensor? Give any four of its applications**.<br>A gas sensor is a device which detects the presence or concentration of gases in the atmosphere.<br>The major applications of gas sensors are<br>•Process control industries<br>•Environmental monitoring<br>•Boiler control<br>•Fire detection<br>•Alcohol breath tests | K1 | CO2 |
| 20 | **Define the terms Conductors and Insulators.**<br>The substances which allow the passage of electric current are known as conductors. E.g. Metals, acids and bases.<br>The substances which do not allow the passage of electric current through them are known as insulators. E.g. Rubber, wood and plastic. | K1 | CO2 |
| 21 | **What is a half cell?**<br>It is a part of a cell containing an electrode dipped in an electrolytic solution. If oxidation occurs at the electrode, that is called oxidation half-cell; if reduction occurs at the electrode, that is called reduction half-cell. | K1 | CO2 |

| | | | |
|---|---|---|---|
| 22 | **What is the relationship between the standard EMF of the cell and the equilibrium constant of the cell reaction at 298K?**<br>$$-\Delta G^{\circ} = nFE^{0} = 2.303RT\log K$$ | K2 | CO2 |
| 23 | **How is an electrochemical cell represented by cell notation?**<br>Anode // Cathode<br>M / $M^{n+}$ // $M^{n+}$ / M | K2 | CO2 |
| 24 | **Using the standard electrode potentials given, predict if the reaction is feasible:**<br>**$Ag^{+}_{(aq)}$ and $Cu_{(S)}$**<br>**$E^{O}_{Cu2+/Cu}$ = 0.34V & $E^{O}_{Ag+/Ag}$ = 0.8V**<br>Cu // Ag<br>$E^{O}_{cell} = E_R - E_L$ = 0.8V - 0.34V = +0.46V<br>$E^{O}_{cell}$ is positive. Hence reaction is feasible. | K3 | CO2 |
| 25 | **Define the following terms: Specific and Equivalent Conductance.**<br>**Specific conductance:**<br>Specific conductance (K) is the reciprocal of specific resistance (or resistivity) of an electrolytic solution, i.e.,<br>$K=1/\rho = 1/AR$<br>**Equivalent conductivity**:<br>It is defined as "the conductance of all the ions present in one equivalent of the electrolyte of the solution at given dilution". If one equivalent of electrolyte is contained in v ml, then<br>$\Lambda_{eq}$ =v x Specific conductance of 1 $cm^3$ solution = v x K | | |

| | | | |
|---|---|---|---|
| 26 | **What is a biosensor?**<br>A biosensor is a device that uses a living organism or biological molecules, especially enzymes or antibodies, to detect the presence of chemicals. | K2 | CO2 |
| 27 | **What are the components used in a glucose biosensor?**<br>The components employed in a glucose biosensor are<br>• Analyte<br>• Bioreceptor<br>• Transducer<br>• Electronics and display | K2 | CO2 |
| 28 | **What are the Common enzymes (bioreceptors) that are used to detect glucose?**<br>The Common enzymes that are used to detect glucose are<br>• Glucose oxidase (GOx)<br>• Glucose dehydrogenase nicotinamide adenine dinucleotide (GDH-NAD)<br>• Glucose dehydrogenase flavin adenine dinucleotide (GDH-FAD)<br>• Glucose dehydrogenase pyrroloquinoline quinone (GDH-PQQ) | K2 | CO2 |
| 29 | **What are the advantages of glucose sensors?**<br>1. It allows patients and clinicians to detect high or low blood glucose levels.<br>2. It helps patients by allowing them to immediately confirm acute hypoglycemia or hyperglycemia.<br>3. The technology facilitates the patients about diabetes and its management by giving the patients more self-care responsibilities.<br>4. It also helps the people to move towards healthy behavior. | K2 | CO2 |

| | | | |
|---|---|---|---|
| 30 | **What is Over voltage ? Mention the causes of over voltage?**<br>Over voltage is the potential difference between anode and cathode in a cell with respect to some reference electrode like saturated Calomel electrode (SCE).<br>**Causes of over voltage**<br>i) The discharge of the ions from the bulk of the solution to the layer on the electrode surface and diffusion across the layers<br>iii) Conversion of atoms to normal start from the deposited substance. It is predicted that any one of the above process may be slow and hence might require excess of voltage. | K2 | CO2 |
| 31 | **What are Ion Selective Electrodes (ISE)?**<br>Ion Selective Electrodes are membrane electrodes that respond selectively to particular ions in the presence of other ions. | K2 | CO2 |
| 32 | **List the advantages of glass electrode?**<br>• It is simple and can be easily used<br>• Equilibrium is rapidly achieved<br>• The results are accurate<br>• It is not easily poisoned | K2 | CO2 |
| 33 | **What are the limitations of glass electrode?**<br>• Generally for the measurement of pH 0-10. Special glass membranes can be used for measurement up to a pH of 12. Above pH 12, cations of solutions affect the glass interface.<br>• Resistance of glass membrane is extremely high- special electronic potentiometers are used to measure the potential of the glass electrode. | K2 | CO2 |

# Part-B Questions

| S.No | PART-B QUESTIONS | K level | CO |
|---|---|---|---|
| 1 | What is electrochemical cell? Explain construction with example of Daniel cell. | K1 & K2 | CO2 |
| 2 | Define EMF. How is it determined? | K2 | CO2 |
| 3 | Differentiate Electrolytic and electrochemical cells | K2 | CO2 |
| 4 | Mention the factors affecting the conductance and explain them. | K2 | CO2 |
| 5 | With a neat sketch explain the principle, working of SHE. | K1 | CO2 |
| 6 | Explain the concept of secondary reference electrode, taking calomel electrode as example. | K2 | CO2 |
| 7 | What is an ion selective electrode? Explain glass electrode with suitable diagram. | K2 | CO2 |
| 8 | What is EMF series? Illustrate the EMF of different metals with their applications. | K1 & K3 | CO2 |
| 9 | Derive Nernst equation? What are the applications? | K1 | CO2 |
| 10 | Explain the principle behind chemical sensors and write its classification. | K2 | CO2 |
| 11 | Write a note on Disposable Breathalyzer | K3 | CO2 |
| 12 | Explain a Non-Dispersive Infrared (NDIR) CO2 Sensor with a neat diagram? | K3 | CO2 |
| 13 | Explain Glucose sensors with its components, mechanism and advantages. | K3 | CO2 |

## Supportive online certification courses

**https://www.udemy.com/course/electro-chemistry/**

**Electro Chemistry**

Electrodes, Electrolytes, Electrochemical cell, fuel cells and Corrosion

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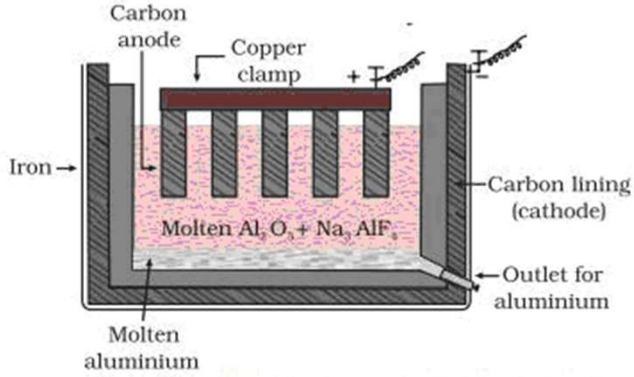
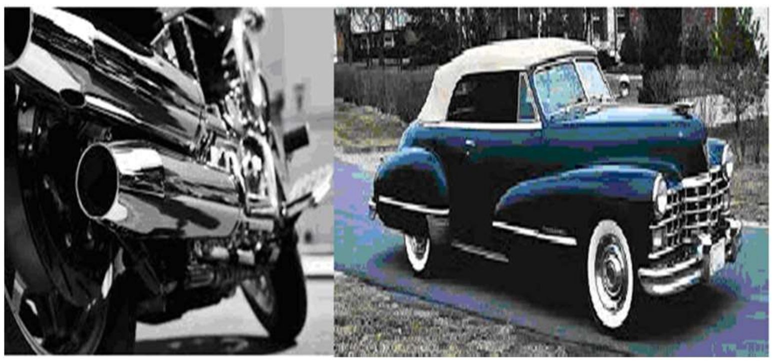
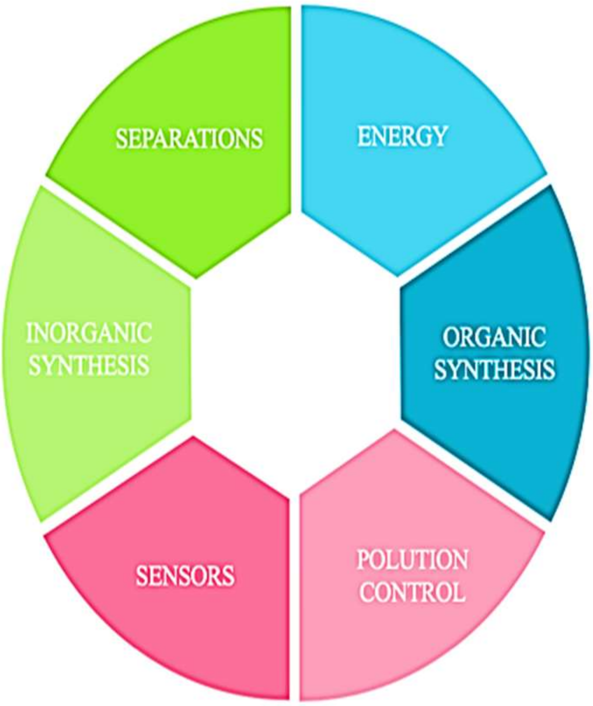
**Sensor and Applications**

## Real time Applications in day to day life and to Industry

| Various Fields | Applications |
|---|---|
| **1. Metallurgy** | Aluminum, titanium, alkaline earth, and alkali metals are obtained by electrodeposition from molten salts, and copper is refined by electrolysis in aqueous copper sulfate solutions.   *Electrolytic cell for the extraction of aluminium* |
| **2. Electroplating**<br>**i) Chromium Plating** | Chrome plating is a technique of electroplating a thin layer of chromium onto a metal object. The chromed layer can be decorative, provide corrosion resistance, ease cleaning procedures, or increase surface hardness.  |

| Various Fields | Applications |
|---|---|
| **ii) Gold Plating** | Gold plating is commonly used in electronics components, most commonly in electrical connectors and printed circuit boards; however, it has other applications. As mentioned above, it can be used in jewellery manufacturing to provide a luxurious gold look atop a more cost-effective silver, nickel, or copper interior.   |
| **iii) Tin Plating** | Tin is electroplated on iron to make cans used for storing food. Electroplating tin makes the container non-reactive and look better.  |

# Applications of Electrochemistry




**SEPARATIONS**
- Salt Splitting
- Electrodialysis

**INORGANIC SYNTHESIS**
- Chlor-alkali manufacture
- Aluminum Refining
- Water Electrolysis
- Halogens, peracids, peroxide, ferrate
- Metals extraction and refining: Al, Na, Mg, Li,

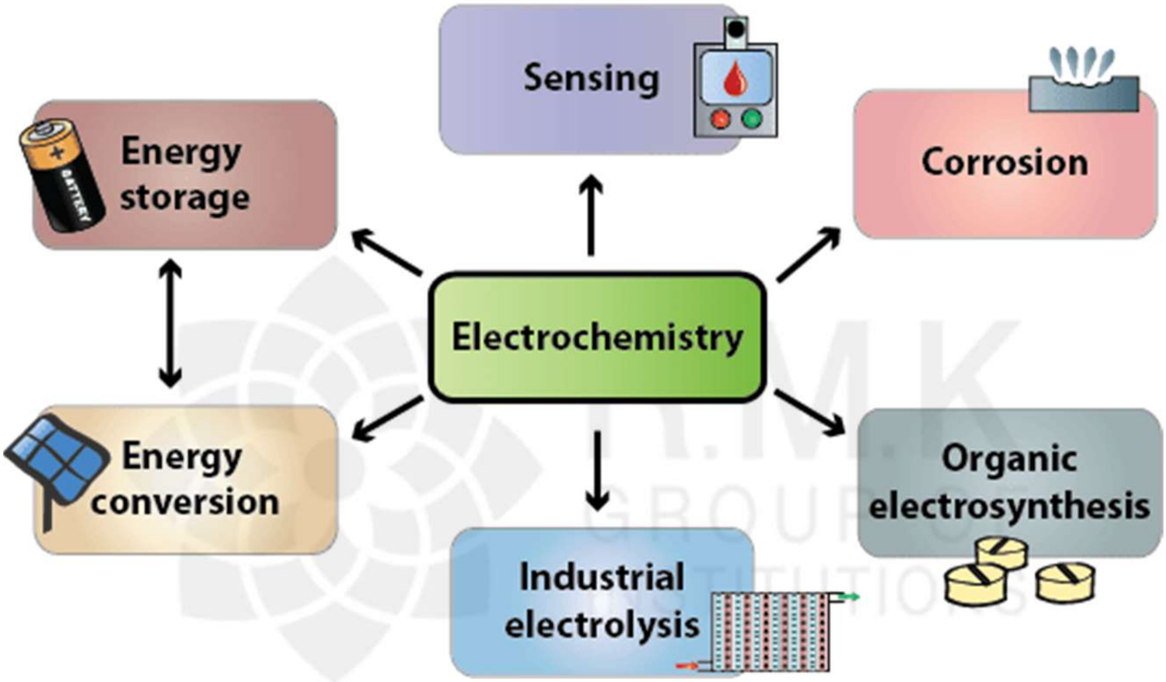
**SENSORS**

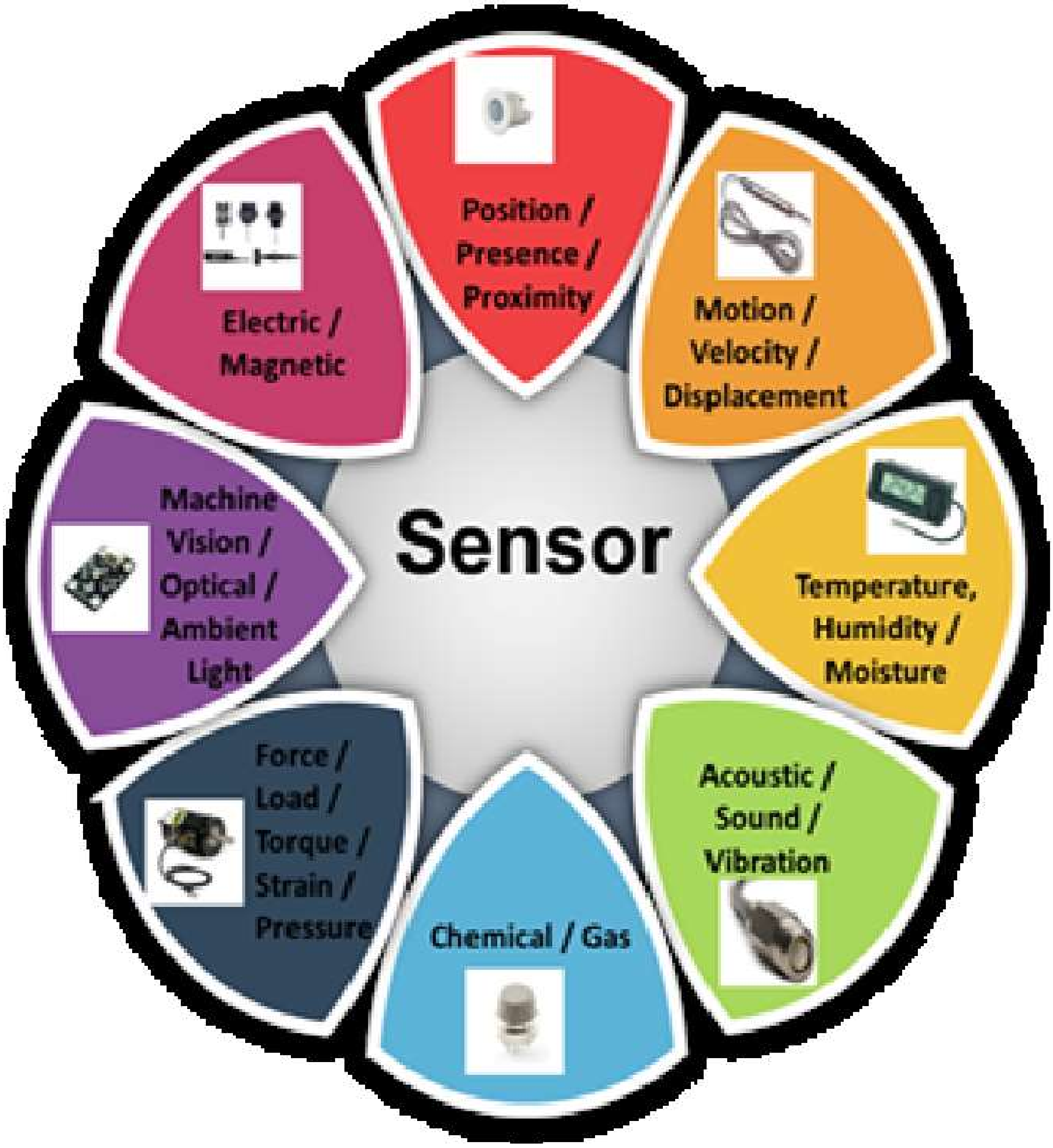
**ENERGY**
- Redox Flow Cells
- Fuel Cells
- Batteries

**ORGANIC SYNTHESIS**
- Halogenation, Dehalogenation
- Methoxylation, Acetoxylation
- Hydrogenation
- Carboxylation and Decarboxylation
- Coupling Reactions
- Nitro Reduction

**POLUTION CONTROL**
- Metal Recovery
- Recycle of chemicals
- Scrubbing of Industrial Gases

## Some technologies based on Electrochemistry






**Application of Sensors in various field**

## Real time Applications in day to day life and to Industry of sensors

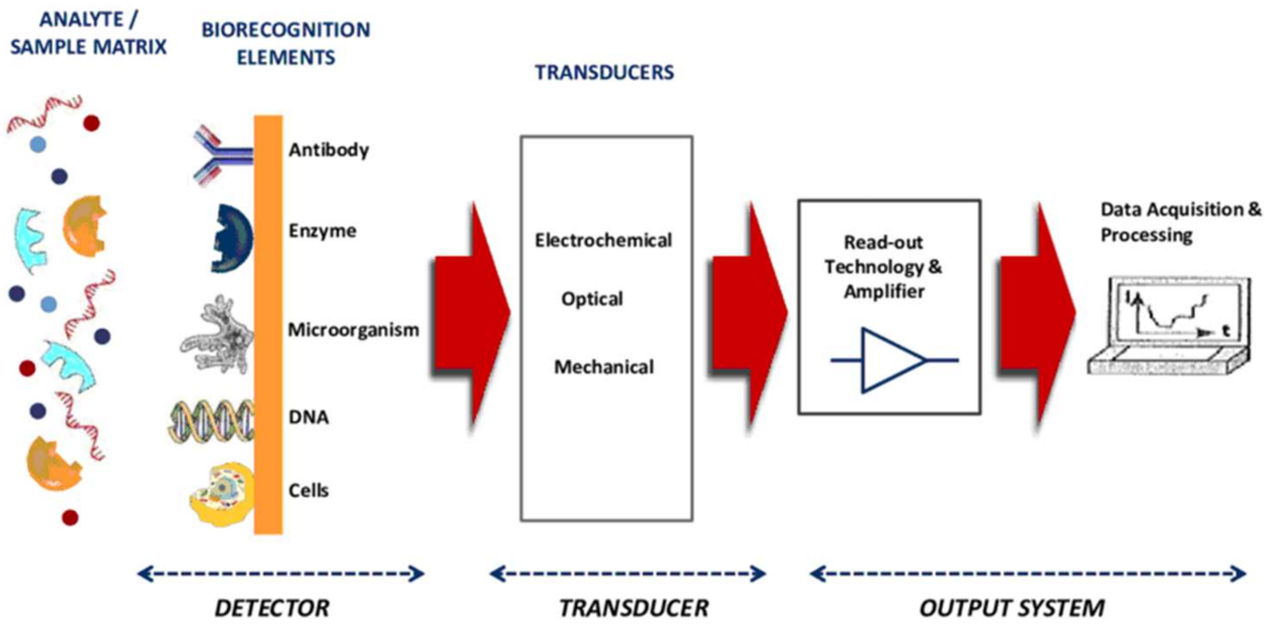
| Various Fields | Applications |
|---|---|
| 1. Automotive | Braking and Traction control: Antilock Braking System (ABS) Sensors connected to the wheel, measures the speed of the wheel and braking pressure and keeps sending them to ABS controlling.<br>Air Bags – Anti Cushion Restraint System (ACRS): Crush sensors and accelerometers placed in the vehicle measures the force and sends it to During accidents on sensing the force exceeds the limit, ACRS will activate the Airbag and save the life of passengers.<br>Engine Data: Sensors provides so much data on Engine performance, such as Ignition, b. Combustion, c. Exhaust gas oxygen, d. Fuel mix, e. Exhaust gas recycling, f. Transmission control etc., |
| 2. Manufacturing | • Predictive maintenance of the machinery, Assembly equipment using the data collected from sensors in the machines.<br>• Optimal utilization of Machines by |

| Various Fields | Applications |
|---|---|
| | continuously monitoring the performances and effectively rejigging the operations with the data collected from sensors.<br>• Fine-tuning the Quality systems and enhance the quality standards using the data collected from sensors. |
| **3. Aviation** | Sensors deployed in the aviation industry measures the data during navigation of aircraft, monitoring various systems, and controlling instruments. These data are utilized inefficient flight operations, improve aircraft performance and design improvements. |
| 4. **Medical & Healthcare** | It is employed in<br>• Blood pressure monitoring (self).<br>• Continuous glucose monitoring by Individuals.<br>• Automatic measurement of vitals of the patient and sending it to the patient's doctor. |
| 5. **Marine** | Sensors in ship measures fuel tank levels, liquid cargo levels, tank pressure/temperature. Pitch, roll, speed and other vessel moments are also measured and monitored with sensors. |

# Content beyond the syllabus

## 1. Biosensors

Biosensors are devices used to detect the presence or concentration of a biological analyte, such as a biomolecule, a biological structure or a microorganism. Biosensors consist of three parts: a component that recognizes the analyte and produces a signal, a signal transducer, and a reader device.




**Example of Biosensor**: Glucometers are a type of Biosensors, which measure the concentration of glucose in blood. Usually, they consists of a test strip, which collect a small sample of blood to analyze the glucose levels. This particular sensor implements the Electroenzymatic approach i.e. oxidation of glucose.

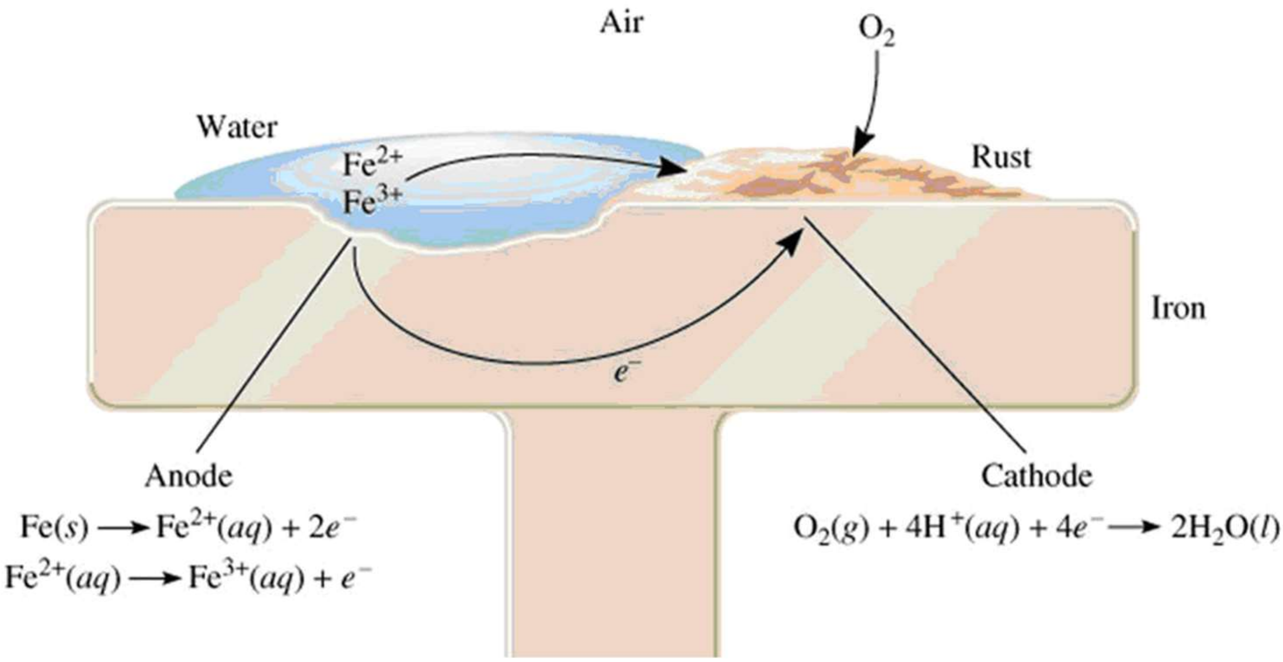
## 2. Electrochemical concepts in corrosion

Corrosion is an electrochemical process, involving the flow of electrons and ions. Corrosion occurs at the anode, protection occurs at the cathode.

Electrochemical corrosion involves the transfer of electrons across metal/electrolyte interface.

Any corrosion cell consists of: Anode, cathode, and an electrolyte.

Deterioration of metal by an electrochemical process

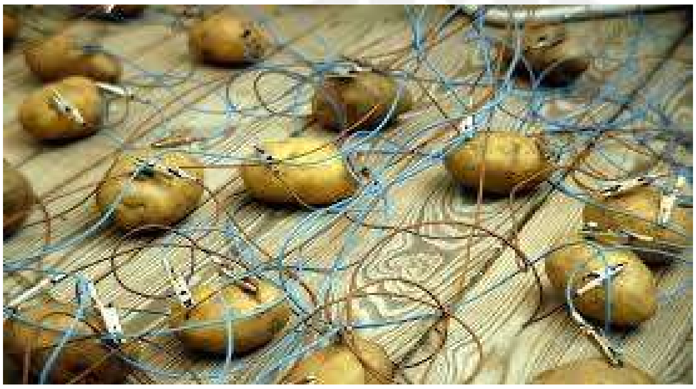


## Different types of Oxygen sensors

| | |
|---|---|
| Electro chemical oxygen sensor | Used to measure oxygen levels in ambient air. It creates an electrical output proportional to the oxygen level based on chemical reaction |
| Zirconia oxygen sensor | The zirconia sensor does not directly sense $O_2$, but rather the difference between the concentration of $O_2$ in the exhaust gas and in the normal air. |
| Optical oxygen sensor | They rely on the use of a light source, a light detector, and a luminescent material that reacts to light. Some molecules or compounds, when exposed to light, will fluoresce (i.e. emit light energy). However, if oxygen molecules are present, the light energy is transferred to the oxygen molecule resulting in less fluorescence. By using a known light source, the amount of light energy detected is inversely proportional to the number of oxygen molecules in the sample. |
| Clark oxygen sensor | The Clark electrode is a type of electrochemical oxygen sensor. It measures oxygen levels in liquid using a cathode and an anode submerged in an electrolyte. |
| Infrared oxygen sensor | Infrared pulse oximeters, commonly called fingertip oximeters, are oxygen sensors that measure the amount of oxygen in the blood by light. |

| | |
|---|---|
| Electro galvanic oxygen sensor | An electro-galvanic oxygen sensor is a fuel cell. Electrical output is produced based on redox reaction and is proportional to the oxygen level inside the sensor. |
| Ultrasonic oxygen sensor | Ultrasonic oxygen sensors use sound speed to measure the amount of oxygen in a gas or liquid sample. |
| Laser oxygen sensor | Tunable Diode Laser (TDL) oxygen sensors rely on spectral analysis. A laser beam at the wavelength of oxygen is directed through a gas sample. The amount of light absorbed by the oxygen molecules is proportional to the number of molecules in the sample. |
| Paramagnetic oxygen sensor | Paramagnetic oxygen sensors rely on the fact that oxygen molecules are attracted to strong magnetic fields. the sample gas is introduced into the sensor and passed through a magnetic field. The flow rate changes in proportion to the oxygen level in the gas. |

## Do it yourself

- Construct Electrochemical cells with fruits and vegetables.

A) insert a copper wire in one fruit

B) insert iron in the second one.

C) Connect using wires

D) Connect an LED bulb

E) Check whether it glows.

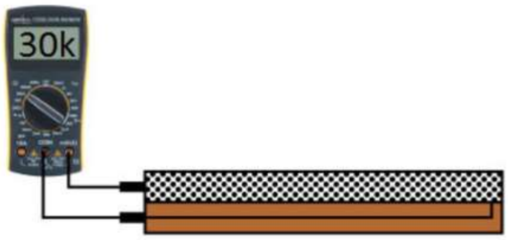
## Do it yourself

### A Flex Sensor

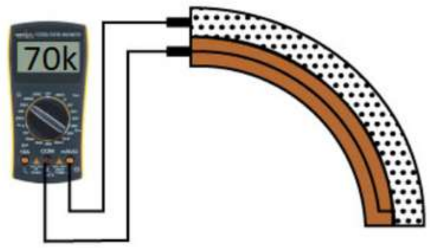
**A flex sensor or bend sensor is a sensor that measures the amount of deflection or bending.** It is also referred to as a **flexible potentiometer**. It works on the principle of resistance and gives out various values based on the variations in resistance.

Its working is very simple. It has a low resistance when it is held straight because of the very low distance between the conductive particles present in the sensor. When it is bent, the distance between the particles increases which leads to higher resistance and a lower current passing through the sensor.

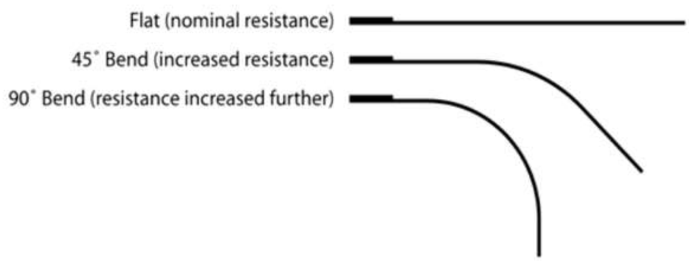
This way we can use a microcontroller board like Arduino very easily as what we need to do is just use the sensor as an input and we will get a value between 0 and 1023 where 0 will be when it is straight and 1023 when it is bent.




Conductive particles close together - 30kΩ.




Conductive particles further apart - 70kΩ.



# Prescribed Text Books & Reference Books

https://www.pdfdrive.com/engineering-chemistry-fundamentals-and-applications-2nd-edition-d191456798.html

Engineering Chemistry Fundamentals and Applications - Shikha Agarwal

http://ia802605.us.archive.org/9/items/textbookofelectr00arrhuoft/textbookofelectr00arrhuoft.pdf

Text-book of Electrochemistry by Svantearrhenius

**Mini Project suggestions**

**UNIT-II**

| | |
|---|---|
| **1.** | **Construct electrochemical cell with different metals and find the EMF.** |
| **2.** | **Design a safety alarm device using sensors.** |
| **3.** | **Find the electrode potential of an unknown electrode using calomel electrode** |
| **4.** | **Construct a thermal sensor** |
| **5.** | **Construct and demo refining of copper** |
| **6.** | **Design an air monitoring device using gas sensors** |
| **7.** | **Construct a Dual Axis Solar Tracking System with Weather Sensor** |
| **8.** | **Tracking of Leg Motion using Compass Sensor** |

# Thank you

**Disclaimer:**