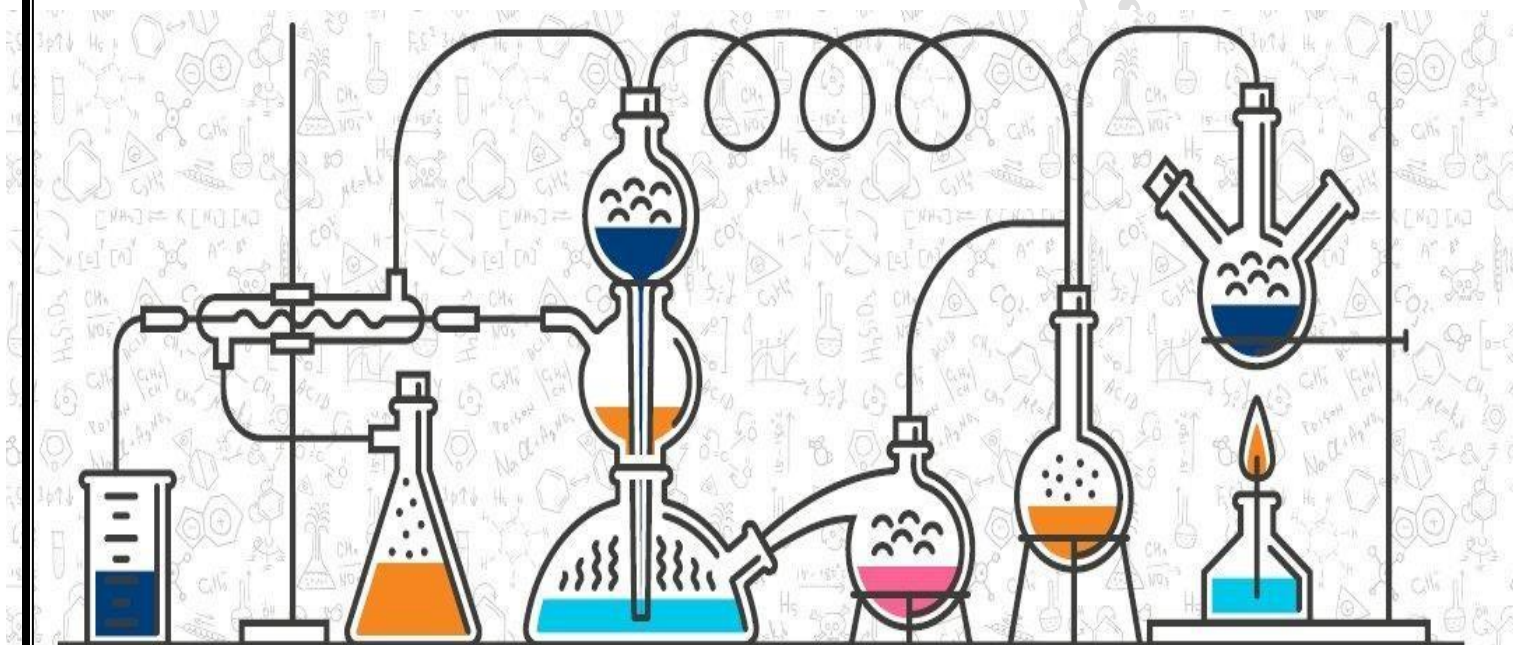




## APPLIED CHEMISTRY- CS Stream

I / II SEMESTER (22CHES12/22)

Sensors and energy Systems



**DAYANANDA SAGAR COLLEGE OF ENGINEERING**

Accredited by National Assessment & Accreditation Council (NAAC) with 'A' Grade  
(An Autonomous Institution affiliated to Visvesvaraya Technological University, Belagavi & ISO  
9001:2015 Certified)

**DEPARTMENT OF CHEMISTRY**

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## MODULE 4

### Sensors and energy Systems

#### Introduction

A sensor is a device that receives a signal (i.e. physical, chemical or biological signal) and responds to the signal in the form of an electrical signal. The output signals correspond to some forms of electrical signal, such as current or voltage.

Components of a sensor

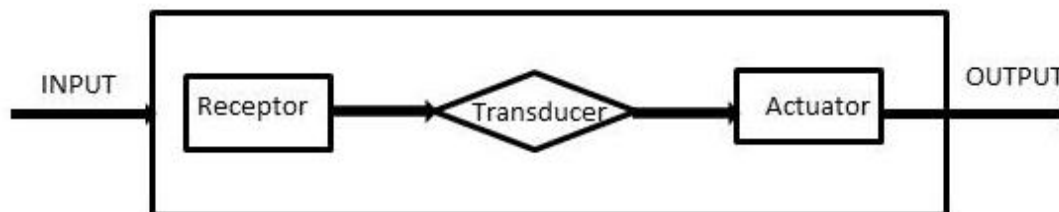


Figure 1: Function of a sensor

1. Receptor- Receives/ observes and acquires information.
2. Transducer-Converts one form of energy into another form.
3. An actuator-Converts electrical energy into mechanical/ readable energy.

#### Electrochemical sensors:

Electrochemical sensors are devices that detect and measure the concentration of the analyte by converting electrochemical reaction between analyte and electrode surface into an electrical signal (electrical signal may be potential, current or conductance).

In electrochemical sensors the electrode or a set of electrodes is used as transducer element. Hence these sensors are often called as Electrochemical cells.

**Types of Electrochemical sensor-** Depending on the mode of signal transduction, electrochemical sensors can be classified in to following types,

1. Potentiometric (measure voltage): Information about the composition of a sample is obtained from the potential difference between two electrodes.
2. Amperometric (measure current): Current is measured with respect to the potential applied between a reference and a working electrode which causes the oxidation or reduction of an electroactive species.
3. Conductometric (measure conductivity): Changes in electrical conductivity/ resistance is measured with respect to the potential applied between a reference and a working electrode which causes the oxidation or reduction of an electroactive species.

**Working Principle of electrochemical cell:** These sensors are often called an electrochemical cell. Electrochemical sensing always requires a closed circuit. Current must flow to make a measurement

In most electrochemical sensors;

- An electrode surface is used as the site of the reaction.
- The electrode will either oxidize or reduce the analyte of interest.
- The current that is produced from the reaction is monitored and used to calculate important data such as concentrations from the sample.

#### Applications of electrochemical sensor:

1. To detect dissolved oxygen in boiler water and to monitor dissolved oxygen concentration in metal melts and glasses.
2. Used in security and defense applications like detection of toxic gases and warfare agents.
3. Used in water analysis and environmental monitoring like measurements of toxic metal concentration in water, pH of water and detection of oxides of nitrogen, sulphur and carbon.
4. Used in soil parameter analysis and in agriculture applications to detect pesticides.
5. Clinical chemistry, namely, the determination of blood glucose,  $\text{Ca}^{2+}$ ,  $\text{Fe}^{2+}$  and uric acid.
6. Used in the detection of enzymes and hormones to monitor cancer.

### Types of electrochemical sensors- Depending on the sensing technique

1. Conductometric sensors
2. Optical sensor
3. temperature

#### Conductometric Sensors:

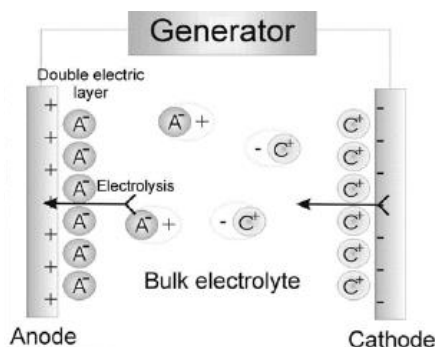
Conductometric sensors are chemical sensors which measure the electrical conductivity/ resistivity of a sample **between two electrodes**. The conductivity is proportional to the concentration of analyte.

#### Principle:

The basic principle of conductometric detection is based on the measurement of specific conductance of an analyte which is dependent on,

- The concentration of ions (number of ions).
- Mobility of ions. Mobility of ion depends on its size. Smaller the size higher is the mobility and higher is the electrolytic conductance.

#### Working:



The conductivity is the result of dissociation an electrolyte into ions. The migration of the ions is induced by an electrical field. When a potential difference is applied to the electrode, there is an electrical field within the electrolyte, so the positively charged ions move towards cathode and negatively charged ions move towards anode(Figure). Thus, the current in the electrolyte is caused by the ion movement towards the electrodes where the ions are neutralized and isolated as neutral atoms (or molecules). The output is measured using a conductometer.

#### Applications:

1. Used to estimate acids, bases and their mixtures in the sample.
2. Used to check the amount of ionic impurities in water samples.
3. Used in measuring acidity or alkalinity of sea water and fresh water.
4. Conductometric biosensors are used in biomedicine, environment monitoring, biotechnology and agriculture related applications.
5. Used in enzyme catalysis to determine analyte concentration and enzyme activity and selectivity.

#### Optical Sensors:

Optical sensors are devices which detect and convert incident light rays into electrical signals.

Example: Colourimetric Sensors

#### Absorption-based optical sensors-Colourimetric Sensors:

Colorimetric sensors are simple type of optical sensors which use incident light of visible region (400-800nm) of spectrum and detect and determine the concentration of coloured chemical species of analyte solutions. The important parts of colorimeter are given below.

**Principle:** Quantitative analysis by colorimetry is based on **Beer-Lambert's law**.

**When a beam of monochromatic radiation is passed through a solution of an absorbing substance. The intensity of incident radiation decreases exponentially with increase in thickness and concentration of the solution.**

$$\log (I_0/I_t) = A = \epsilon Cl$$

$I_0$  = intensity of the incident light

$I_t$  = intensity of transmitted light

A = absorbance

$\epsilon$  = molar absorption co-efficient

l = length of light path

C = concentration

The term,  $\log (I_0/I_t)$  is called the absorbance or optical density of the light absorbing medium. Since  $\epsilon$  is a constant and thickness l is kept constant.

### Working:

When analyte solution interacts with an incident light of suitable wavelength, certain quantity of light is absorbed by the analyte solution, and a transducer such as photo detector converts intensity of light absorbed by analyte into electrical signal.

A monochromatic light whose wavelength falls in visible region of spectrum is made to pass through analyte solution where certain quantity of incident light is absorbed and remaining amount of light is transmitted. Concentration of coloured chemical species in analyte solution is determined by measuring absorbance or transmittance of light of particular wave length.

### Applications of optical sensors:

- Used to detect and measure different types of chemical, biochemical molecules and ions.  
Example: Ions in solution (pH, metal ions and anions), gases ( $\text{CO}_2$ ,  $\text{O}_2$ ,  $\text{NH}_3$ ,  $\text{SO}_2$ ,  $\text{NO}_2$ ,  $\text{NO}$  etc).
- Used in imaging, remote sensing satellite, metrology, medical devices and quality process control-based applications.
- Breath analyzers: used to detect alcohol consumption.
- Biomedical and healthcare applications (dentistry to measure blood flow in the teeth, Contactless sanitizer dispensers)
- Industrial and Agricultural applications
- Optical sensors are used in smart phones for adjusting the brightness of the screen, smart watches to measure the heartbeat of the person, as essential parts in devices like Xerox machines, computers & light fixtures.
- Biometrics applications.

### Temperature sensor

It is an instrument designed to detect the level of coolness or hotness of an object which gives temperature measurement in the readable form via an electrical signal.

**Principle:** The sensor is made up of two metals, which generate electrical voltage or resistance once it notices a change in temperature.

**Working:** Main component of a thermometric sensor is a small tubular catalytic reactor fitted with a temperature transducer. Analyte is fed into the reactor where it undergoes reaction, liberating heat energy. Heat liberated results in change in temperature which is converted to the output voltage by transducer such as thermocouple, then signal is amplified and fed to the data storage , processing unit and display.

### Applications:

1. **Home appliances** – kettles, toasters, washing machines, dishwashers and coffee machines will all contain temperature sensors.
2. **Computers and Integrated circuits**– within computers or **Integrated circuits** there are temperature sensors to ensure the system does not overheat.
3. **Vehicles** use temperature sensors within their radiator.
4. **Glass manufacturing** -relies on temperature measurement for the regulation and optimization of their production process.
5. **Chemical industries** -They are required to measure extremely high temperatures to monitor chemical reactions.

### Construction of electrochemical cell

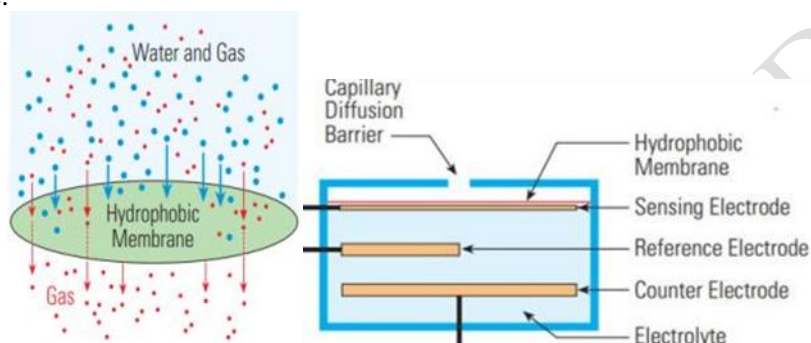
- Electrochemical sensor consists of a sensing electrode (or working electrode), a counter electrode and a reference electrode in electrolyte.
- The sensing electrode has a chemically modified surface, facilitating the reduction or oxidation of the analyte.
- The role of electrolyte is to transport charge within the sensor and contact all electrodes effectively.

### Electrochemical gas sensors:

Gas sensors detect chemicals in the gas phase. They operate by reacting with the gas of interest and producing an electrical signal proportional to the gas concentration. Electrochemical sensors are used to detect the presence of toxic gases such as  $\text{H}_2\text{S}$ ,  $\text{Cl}_2$ , and  $\text{SO}_2$ , and variation of oxygen in the air.

Similar to other electrochemical sensors, except in this case gases diffuse through a membrane to be reduced or oxidized at an electrode.

### Working Principle:

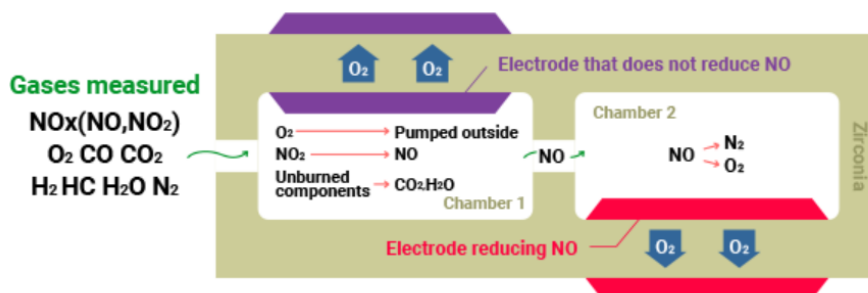


- Gas that comes in contact with the sensor first passes through a small capillary-type opening, filter and then diffuses through a hydrophobic barrier, and finally reaches the electrode surface.
- Adsorption of analyte gas molecule on the surface of sensing electrode.
- A suitable voltage is applied to the sensing electrode and that makes the sensor specific to the target gas.
- The analyte gas reacts at the surface of the sensing electrode involving either an oxidation or reduction mechanism.
- Current proportional to the gas concentration flows between the working electrode and counter electrode is measured. Concentration of analyte gas is determined on the basis of current flow.

### Electrochemical gas sensors for NO<sub>x</sub>:

The detection of nitrogen oxide is of crucial importance in the environment monitoring. Nitrogen oxides, NO and NO<sub>2</sub>, denoted generally as NO<sub>x</sub>, are formed during the fuel burning in stationary sources (energy plants) and in the automobiles' engines, from the elements of the air, in the harsh conditions (high temperatures, especially in case of Diesel engines).

**Working principle:** Automotive NO<sub>x</sub> sensors are primarily of the amperometric type, with two electrochemical cells in adjacent chambers. Pt-Au alloy electrode is used as working electrode, Pt-Rh alloy electrode as counter electrode and Zirconia-based solid electrolyte is used in NO<sub>x</sub> sensors.





1. In Chamber 1, any oxygen present in the exhaust gas is removed or electrochemically pumps  $O_2$  out of the sample so it does not interfere with the  $NO_x$  measurement in the second cell.
2. In Chamber 1, combustible gases present in the exhaust gas are burned.
3. In Chamber 1,  $NO_2$  present in the exhaust gas is converted to  $NO$ .  

$$NO_2 \longrightarrow NO + \frac{1}{2} O_2$$
4. In Chamber 2, the  $NO$  is decomposed by the reduction catalyst, and the amount of oxygen generated at the time of decomposition is measured. Pt-Rh alloy electrode can be used to catalyze the reduction of  $NO_x$ .  

$$2NO \longrightarrow N_2 + O_2$$
5. The corresponding current is measured which indicates the concentration of the  $NO_x$  gas.

### Function of $NO_x$ sensors

1. Reduction of emission of harmful  $NO_x$
2. Environmentally friendly

### Analytical Techniques: Introduction

In instrumental analysis, a physical property of a substance is measured to determine its chemical composition. Instrumental methods of analysis can be classified into two types.

#### 1. Electrical methods

This method of analysis involves the measurement of current, voltage and resistance in relation to the concentration of a certain species in solution.

Examples: - Conductometry, Potentiometry.

#### 2. Optical methods

This method of analysis involves the measurement of absorption and emission of light by the substance in solution, which is related to concentration of a certain species in solution.

Examples: - Colorimetry, Flame photometry.

### Colorimetric sensors: Estimation of copper

Colorimetric analysis involves measurement of quantity of light absorbed by a colored solution.

**Principle:** Quantitative analysis by colorimetry is based on **Beer-Lambert's law**.

$$A = \epsilon Cl$$

A = absorbance

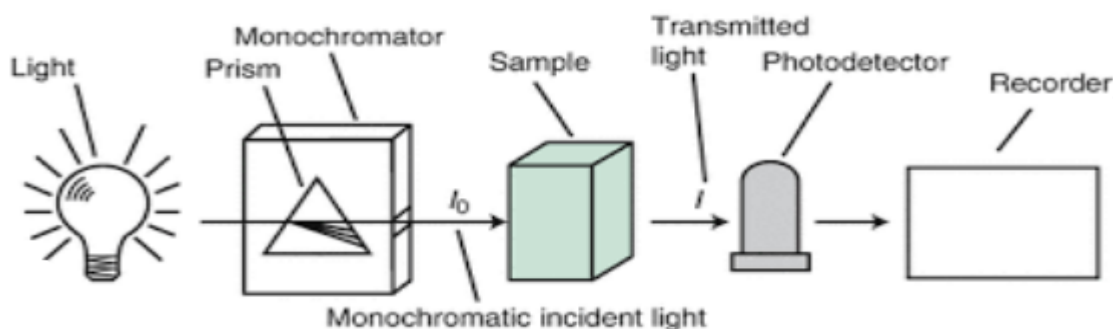
$\epsilon$  = molar absorption co-efficient

l = length of light path

C = concentration

**Light Source** – The most common source of light used in colorimeter is a tungsten filament.

**Monochromator** – To select the particular wavelength filter or monochromators are used to split the light from the light source.



### Fig: Block diagram of photoelectric colorimeter

**Sample holder** – Test tube or Cuvettes are used to hold the color solutions they are made up of Glass at the visible wavelength.

**Photo Detector System** – when light falls on the detector system, an electric current is generated, this reflects the Galvanometer reading.

**Measuring device (recorder)** – The current from the detector is fed to the measuring device, the Galvanometer, shows the meter reading that is directly proportional to the intensity of light.

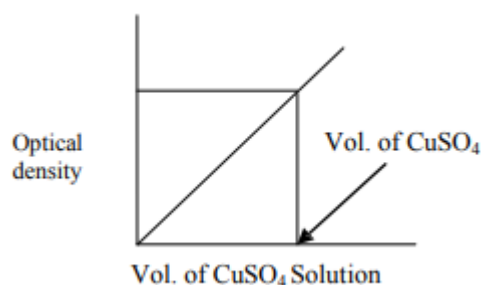
Transfer the given copper sulphate solution (stock solution) to a burette and draw out 5, 10, 15, 20 and 25 cm<sup>3</sup> of the solution into 50 cm<sup>3</sup> volumetric flasks. Add 5 cm<sup>3</sup> of ammonia solution to each of them and dilute up to the mark with ion exchange water. Stopper the flasks and mix. To the test solution given in a 50 cm<sup>3</sup> volumetric flask, add 5 cm<sup>3</sup> of ammonia and dilute upto the mark and mix well. Prepare a blank solution by diluting 5 cm<sup>3</sup> of ammonia solution in a 50 cm<sup>3</sup> volumetric flask up to the mark with ion exchange water and mix well. Measure the absorbance of the solutions against blank at 620 nm using photoelectric colorimeter. Draw a calibration curve by plotting optical density (OD) against volume of copper sulphate (cm<sup>3</sup>). Using the calibration curve, find out the concentration of copper in the test solution and calculate the amount of copper in 50 cm<sup>3</sup> of the given test solution.

A series of standard solutions containing Cu(II) ions is treated with NH<sub>3</sub> to get dilute solution of the complex of cuprammonium complex ion



Maximum absorbance of these complex ion is 620nm.

Flask No	Volume of NH <sub>3</sub> (cm <sup>3</sup> )	Volume of copper sulphate solution (cm <sup>3</sup> )	Absorbance (Optical Density)
Blank (B)	5	0	
1	5	5	
2	5	10	
3	5	15	
4	5	20	
5	5	25	
TS	5	Test solution	



The reason for getting a straight line is because it follows, **Beers Lamberts Law**

### CONDUCTOMETRIC TITRATIONS:

#### **Conductometric sensor: Estimation of weak acid**

**Principle:** The electrical conductance depends on the concentration of solution and mobility of ions.

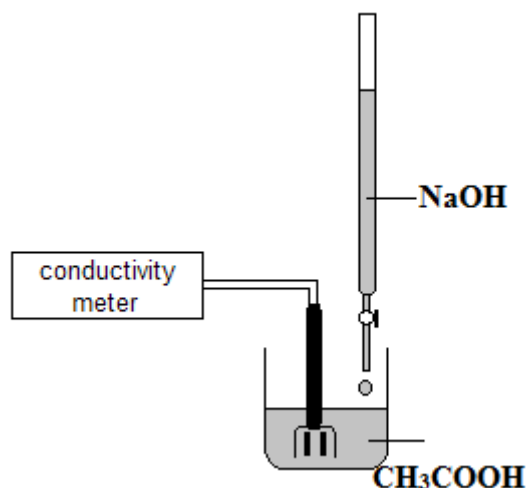
Analysis based on measurements of conductivity of solution is called **conductometric analysis**. The migration of ions is responsible for the conduction of electricity in solutions.

Conductance is defined as the reciprocal of resistance.

$$C=1/R \quad \text{Where } R \text{ is resistance}$$

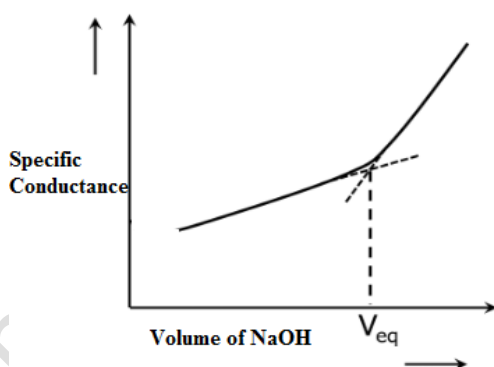
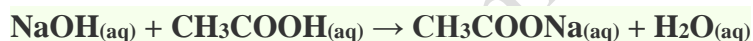
The unit of conductance is ohm<sup>-1</sup> or Ω<sup>-1</sup>. The SI unit is Siemen(S).

Conductivity cells are usually made of quartz, which consist of two electrodes of platinum plates sealed into glass tubes. The conductivity cell is connected to conductometer.



### Procedure:

The acetic acid is taken in the beaker and immersed conductivity cell into it and NaOH in the burette. The conductance of the acid will be low because of its poor dissociation. On adding, the NaOH, highly ionized sodium acetate is formed and hence the conductance begins to increase. When the acid is completely neutralized, further addition of NaOH introduces excess of fast moving  $\text{OH}^-$  ions. The conductance of the solution begins to increase sharply. The intersection extrapolated to X-axis gives the volume of NaOH consumed by acetic acid for neutralization.



Sl. No	Volume of NaOH added ( $\text{cm}^3$ )	Conductivity ( $\text{Ohm}^{-1} \text{cm}^{-1}$ )
1.	00	
2.	0.5	
3.	1.0	
4.	1.5	
5.	2.0	
6.	2.5	
7.	3.0	
8.	3.5	
9.	4.0	
10.	4.5	

### Calculation

$$V_1 N_1 (\text{CH}_3\text{COOH}) = V_2 N_2 (\text{NaOH})$$

$$\text{Strength of acetic acid } N_1 = V_2 N_2 / V_1 = \underline{\text{a}} \text{ N}$$

$$\text{Weight of acetic acid} = \text{Strength of acetic acid} \times \text{equivalent weight of acetic acid (60)}$$

$$= \text{a} \times 60 = \underline{\text{b}} \text{ g/litre.}$$

**Result:** The weight of acetic acid present in the given solution is = b g/litre.



## Potentiometric titrations

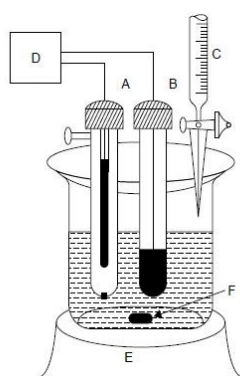
### Potentiometric sensors: Estimation of iron

**Principle:** The potential of an electrode depends on the concentration of the solution.

Potentiometric titrations involve in measurement of electrode potentials with addition of titrant. The electrode potential is given by Nernst equation

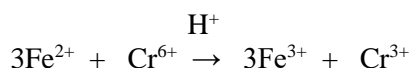
$$E = E^0 + \frac{2.303RT}{nF} \log[M^{n+}]$$

The potentiometric titration requires the selection of the appropriate indicator electrode and reference electrode is usually a **platinum** and **saturated calomel electrode**, respectively.



**Fig.** Potentiometric titration assembly

Take 25 cm<sup>3</sup> of the given FAS solution into a clean beaker and add 2 test tubes of dil. H<sub>2</sub>SO<sub>4</sub>. Immerse platinum electrode and saturated calomel electrode assembly, connect to a potentiometer and note down the potential value in milli volts (mV). Fill a micro burette with the given standard K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> solution. Add K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> solution in increments of 0.5 cm<sup>3</sup> to FAS solution in the beaker. Stir the solution thoroughly and measure the emf after each addition. When the reaction reaches the equivalence point, there is a maximum increase in the emf value. After the equivalence point, there will be slight increase in emf on continued addition of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>. Graph of E/ V against volume of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> is plotted. From the graph, volume of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> at equivalence point is found out.

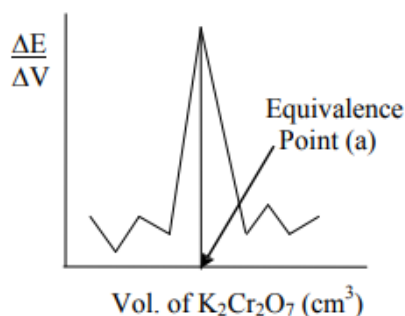


At the equivalence point, there will be sudden jump So the increase in the value of Fe<sup>3+</sup>/Fe<sup>2+</sup> and change in the electrode from Pt/ Fe<sup>3+</sup>, Fe<sup>2+</sup> (0.77V) to Pt/Cr<sup>6+</sup>, Cr<sup>3+</sup> (1.33V), there is a huge change in potential at the end point.

$$E = E^0 + 0.0591 \log \left[ \frac{\text{Fe}^{2+}}{\text{Fe}^{3+}} \right]$$

The ΔE/ΔV plotted against the volume of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> added, the end point where the slope of curve is maximum.

Volume of $K_2Cr_2O_7$ ( $cm^3$ )	E (mV)	$\Delta E$	$\Delta V$	$\frac{\Delta E}{\Delta V}$
0		NIL	NIL	NIL
0.5				
1.0				
1.5				
2.0				
2.5				
3.0				
3.5				
4.0				
4.5				
5.0				



### Calculation

Normality of  $K_2Cr_2O_7$  = N (will be given) ----- (b)

Normality of FAS = Normality of  $K_2Cr_2O_7$   $\times$  Volume of  $K_2Cr_2O_7$  (from graph)/Volume of FAS

$$N = b \times a / 25 = \text{-----} N (z)$$

Weight of FAS / $dm^3$  = Normality of FAS  $\times$  Equivalent weight of FAS (392.24)

$$= z \times 392 \text{ g} = \text{-----} \text{g/litre (w)}$$

**Result:** Weight of FAS in given solution = -----g/litre

## Energy Systems

### Energy Conversion Devices

Energy conversion is the transformation of one form of energy into another form. More specifically, the term energy conversion refers to the process through which energy is changed into forms that are useful to humans.

**Battery:** A Battery is a combination of two or more electrochemical cells arranged in series or parallel which converts the chemical energy into electric energy by electrochemical redox reactions.

### Classification of batteries

#### 1. Primary batteries

1. In primary batteries, the chemical energy is converted into electrical energy as long as the chemical components are active.
2. These batteries the reaction occurs only once and after that they must be discarded.
3. These batteries cannot be recharged as the chemical reactions which occur within the primary batteries are irreversible.

Examples: Zn- air battery, Dry cell, Li-  $MnO_2$

#### 2. Secondary batteries

1. Secondary batteries are those which after discharging can be recharged.
2. These batteries chemical reactions taking place are reversible
3. The redox reaction which converts chemical energy into electrical energy can be reversed by passage of current.
4. The electric energy is stored in the form of chemical energy these batteries are also known a storage

cell.

Example: Lead storage battery, Nickel-cadmium battery, Nickel-metal hydride battery and Lithium-ion battery.

### 3. Reserve Batteries

1. These batteries one of the components is isolated and incorporated into the battery when required.
2. The electrolyte is the component that is isolated, but some water activated batteries contain the electrolyte solute and water is added for activation.
3. They are used to deliver high power for relatively short periods of time in application such as radiosondes (air borne instruments to send meteorological information back to earth by radio).

Examples: Mg batteries activated by water (Mg-AgCl, Mg-CuCl), Zn-Ag<sub>2</sub>O batteries etc

### Components of battery

Typical household battery: container, cathode, separator, anode, electrodes, electrolyte, and collector.

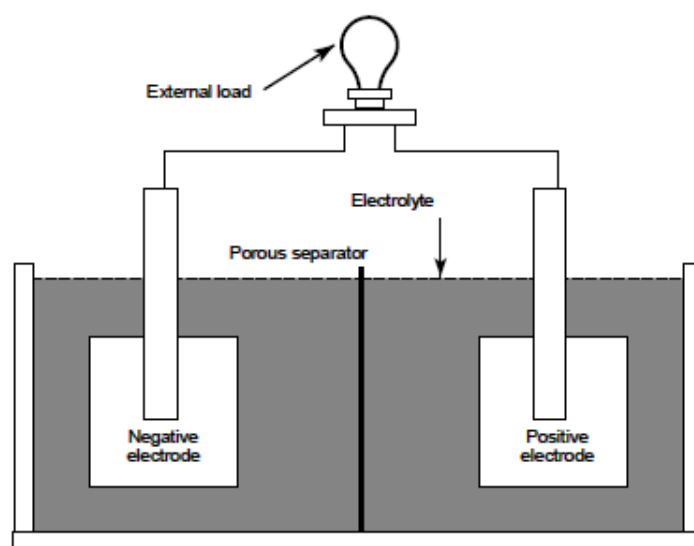


Fig: Components of battery

### Na-ion battery

Sodium-ion batteries are a potential alternative to lithium-based battery technologies, largely due to sodium's lower cost and greater availability. Na-ion battery is a type of rechargeable battery that uses sodium ions ( $\text{Na}^+$ ) as its charge carriers. Its working principle and cell construction are almost identical with those of lithium-ion battery types, but replace lithium with sodium.

#### Construction

**Anode:** carbon (C<sub>6</sub>) anode

**Cathode:** layered transition metal oxide,  $\text{NaMO}_2$ ,

**Electrolyte:** Sodium hexafluorophosphate is an inorganic compound with the chemical formula  $\text{Na}[\text{PF}_6]$ .

**Separator:** poly olefin/polypropylene.

#### Working

1. During discharging sodium atoms present in the carbon anode undergo oxidation, liberating Na ions and electrons. Na ions migrate from anode to cathode through electrolyte through the separator which selectively allows only the Na ion to pass through and block the flow of electrons inside battery.
2. At cathode, Na ions are reduced to sodium metal and are inserted in to the structures of metal oxide.
3. During charging of the battery, sodium metal present in the structure of metal oxide get oxidized

liberating Na ions and electrons. The liberated Na ion moves through the separator towards the carbon electrode (anode).

- At the anode, Na ions get reduced to sodium metal and gets inserted into the layered structure of carbon.

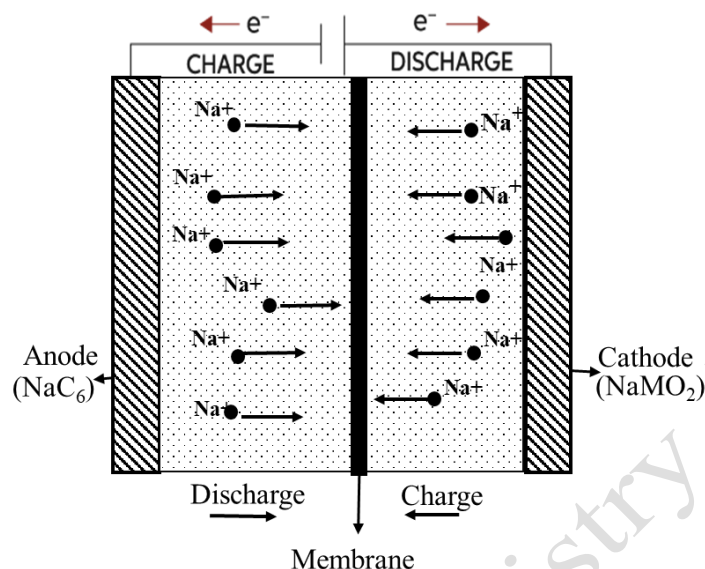
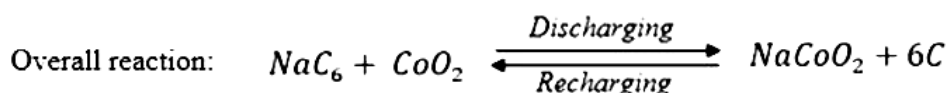
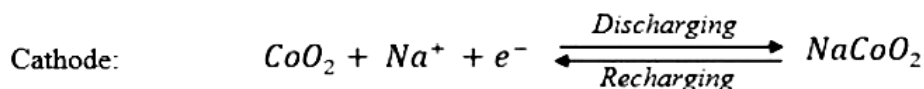
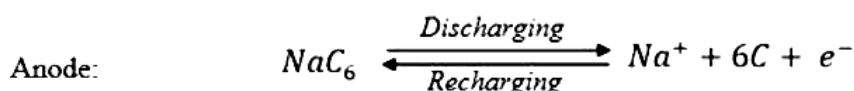


Fig: Na-ion battery



Sodium-ion batteries have several advantages over competing battery technologies. Compared to lithium-ion batteries, sodium-ion batteries have somewhat lower cost, slightly lower energy density, better safety characteristics, and similar power delivery characteristics.

#### Application of sodium ion battery:

- Sodium-ion batteries have shown great promise for large scale storage of renewable energy.
- Sodium-ion batteries are cheaper and last longer than cell currently used in gadgets.
- These factors price, abundance and size, make sodium-ion batteries particularly interesting for large scale grid storage application.

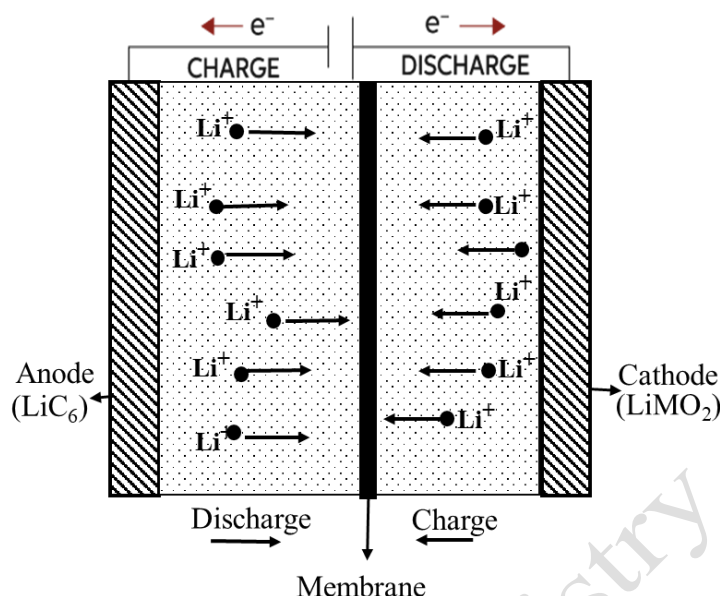
#### Advantages of sodium ion battery

- Rechargeable sodium ion for energy storage.
- Easier to recycle
- Low market prices
- Capable of working at room temperature, good efficiency.

#### Disadvantages of sodium ion battery.

- Large ionic size  $\text{Na}^+$  which require more power to keep energy flowing.
- It takes seven days to charge in case you forget to charge it.
- Lower operating voltage.

### Li-ion Battery



**Fig: Li-ion battery**

#### Construction

**Anode** (-ve electrode): Lithiated carbon

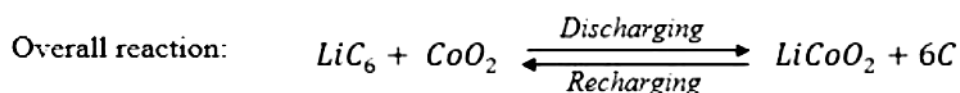
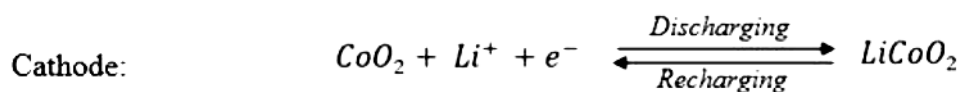
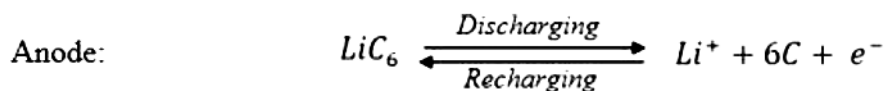
**Cathode** (+ve electrode): Lithiated metal oxide LiMO<sub>2</sub> (M=Co, Mn, Ni)

**Electrolyte:** LiPF<sub>6</sub> in dimethyl carbonate and ethylene carbonate.

**Separator:** poly olefin/polypropylene.

#### Working

1. The anode and cathode store the lithium. During discharging Li atoms present in the graphite layer are oxidized, liberating Li ions and electrons. Li ions migrate from anode to cathode through electrolyte through the separator which selectively allows only the Li ion to pass through and block the flow of electrons inside battery.
2. At cathode, Li ions are reduced to Li atoms and are inserted in to the structures of metal oxide.
3. During charging of the battery, Li atoms present in the structure of metal oxide get oxidized liberating Li ions and electrons. The liberated Li ion moves through the separator towards the graphite carbonate electrode (anode).
4. At the graphite electrode, Li ions get reduced to Li atoms and gets inserted into the layered structure of graphite.



### Applications:

It is used in cell phones, laptops, automobiles, defense and aerospace applications.

### Li-ion battery has more advantages than traditional rechargeable battery:

- High voltage: Lithium batteries have voltages up to about 4 V, depending on the cathode material,
- highly stable
- wide operating temperature (ie. from  $-40^{\circ}\text{C}$  to  $+70^{\circ}\text{C}$ )
- Flat discharge Characteristics
- High specific energy and energy density.

## FUEL CELLS

### Introduction:

- The electrochemical conversion of the free energy change of redox reaction into electrical energy is working principle of any type of cell.
- The electrode reaction of primary batteries is irreversible and the cell produces EMF as long as the active materials are present in the cell.
- Secondary batteries are reversible. It can be changed to give EMF.
- A fuel cell is an electrochemical cell which can convert the chemical energy contained in a fuel-oxidant system into electrical energy by an electrochemical process.
- Fuels cell consists of fuel an oxidant and electrolyte and two electrodes. The reactions that produce electricity take place at the electrodes. The fuel and the oxidant are supplied continuously.

### Definitions:

A fuel cell is defined as galvanic cell in which the electrical energy is directly derived by the combustion of chemical fuels supplied continuously. It is a device that oxidizes as fuel.

(Hydrogen, natural gas, Methanol, gasoline etc.) and an oxidant (oxygen) into electricity.

### Fuel cell advantages

- They offer high energy conversions
- They produce energy as long as fuel and oxidant are supplied.
- Silent operation.
- They are eco-friendly as the product of the overall reactions are non-toxic
- No need of charging.

### Fuel cells limitation/ disadvantages

- The electrodes used are Pt, Ag, or the alloys noble metals which are costly.
- Fuels and oxidant need to be stored in tanks under high pressure.
- Power output by a single unit is moderate.
- These are only energy conversion devices and not energy storage devices.

### Difference between conventional battery and a fuel cell

Conventional Batteries	Fuel cells
1. Batteries store electrical energy in the form of chemical energy and supplies it whenever required	1. Fuel cell produce electricity on the spot
2. Secondary batteries need charging	2. Fuel cells do not need charging. They are not chargeable in conventional manner.
3. The reactants and products from an internal part of batteries	3. Reactants are continuously supplied and the products are constantly removed.
4. The products are not removed continuously	4. The products are continuously removed from the cell



### Methanol-oxygen fuel cell

Direct Methanol Fuel Cell (DMFC) is a fuel cell that runs directly on methanol (or various liquid fuels) without having to first convert those fuels into hydrogen gas.

Methanol is preferred as a fuel because it is one of the most electro active organic fuels in low temperature range due to the following reasons.

1. It has low carbon content
2. It possesses a readily oxidizable – OH group.
3. It has high solubility in aqueous solution.

Components: **Electrode:** Pt

**Fuel:** CH<sub>3</sub>OH (Methanol)

**Oxidant:** Oxygen

**Electrolyte:** 3.47 M H<sub>2</sub>SO<sub>4</sub>

**Separator:** proton exchange membrane (PEM)- Nafion

### **Construction**

1. Methanol is a Fuel and O<sub>2</sub> is act as Oxidant.
2. Both Anode & Cathode is porous Nickel sheet coated with electro catalyst.
3. Pt-Pd catalyst is deposited on anode and Ag is coated on cathode.
4. Methanol mixed with Water is passed through Anode chamber.
5. Pure Oxygen is passed through Cathode chamber.
6. To prevent the diffusion of Anode reactant Methanol into cathode chamber, a Proton conducting membrane is placed near Cathode.
7. The PEM only allows Proton's [H<sup>+</sup>] to Cathode.

### **Working**

#### Reactions

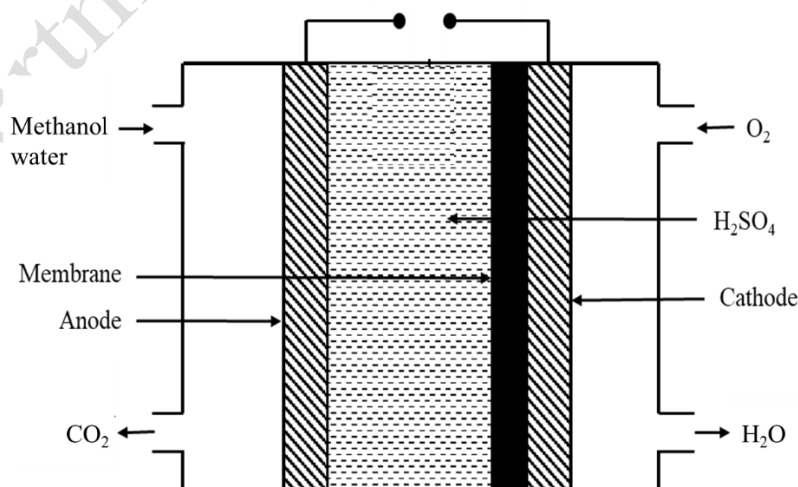
**Anode reaction** -: CH<sub>3</sub>OH + H<sub>2</sub>O → CO<sub>2</sub> + 6H<sup>+</sup> + 6e<sup>-</sup>      E<sup>0</sup> = 0.02V

**Cathode reaction** -: 3/2 O<sub>2</sub> + 6H<sup>+</sup> + 6e<sup>-</sup> → 3H<sub>2</sub>O      E<sup>0</sup> = 1.23V

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**Overall reaction** -: CH<sub>3</sub>OH + 3/2 O<sub>2</sub> → CO<sub>2</sub> + 2H<sub>2</sub>O      E<sup>0</sup> = 1.21V

At anode, the methanol is oxidized into carbon dioxide and six protons (as hydronium ions) plus six electrons. The six protons formed react at the cathode with oxygen to form water. The overall reaction looks like a combustion reaction and is thus sometimes referred to as cold combustion. Actually the cell is a mean to control this reaction and use it to produce current directly. The standard cell voltage for a DMFC at 25°C is 1.21V. However, this potential is never obtained in reality. The open circuit potential is usually about 0.6 to 0.8V.



**Fig: Methanol-oxygen fuel cell**

### **Applications**

1. Using a liquid fuel for power.
2. The cells find application in military and large-scale power production.
3. A simpler system design, with the potential for low-volume, lightweight packaging.
4. Eliminating the requirement for fuel reforming and/or onboard hydrogen storage.
5. Classification as a zero-emission power system.

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