Module: 1

Sensors and Energy Systems

Syllabus
Sensors: Introduction, working principle and applications of Conductometric sensors, Electrochemical sensors, Thermometric sensors, and Optical sensors. Sensors for the measurement of dissolved oxygen (DO). Electrochemical sensors for the pharmaceuticals, surfactants, hydrocarbons. Electrochemical gas sensors for SOx and NOx. Disposable sensors in the detection of biomolecules and pesticides. **Energy Systems**: Introduction to batteries, construction, working and applications of Lithium ion and Sodium ion batteries. Quantum Dot Sensitized Solar Cells (QDSSC's)- Principle, Properties and Applications. **Self-learning:** Types of electrochemical sensor, Gas sensor - O2 sensor, Biosensor – Glucose sensors.
Course Outcomes
CO1: Identify the terms and processes involved in scientific and engineering applications
CO2: Explain the phenomena of chemistry to describe the methods of engineering processes
CO3: Solve for the problems in chemistry that are pertinent in engineering applications
CO4: Apply the basic concepts of chemistry to explain the chemical properties and processes
CO5: Analyze properties and processes associated with chemical substances in multidisciplinary situations

Energy Systems:

Introduction:-

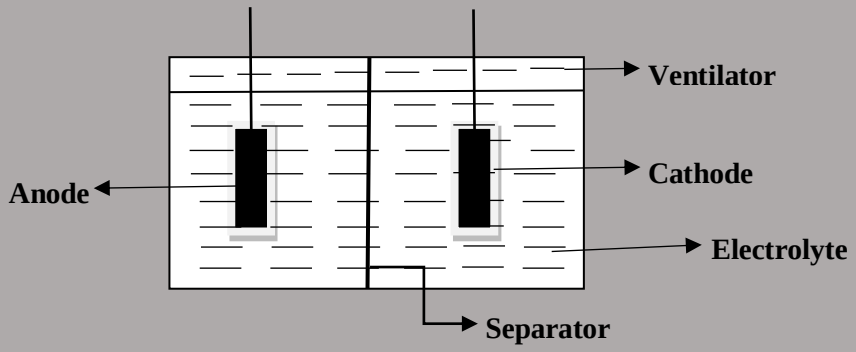
- A battery is a device that consists of two (or) more galvanic cells connected in series (or) parallel (or) both which converts chemical energy into electrical energy through redox reactions.
- A device enables the energy liberated in a chemical reaction to be converted directly into electricity.
- A battery is a portable energy source with three basic components an Anode, a Cathode and an Electrolyte.
  Ex: - Lead-Acid battery, Nickel-Cadmium battery, etc.…
- The size of the present day batteries ranges from a fraction of a cubic centimeter to several cubic decimeters.
- Batteries are used in calculators, digital watches, telephones, tape-records, car engines, etc.…
- A battery is always designed and manufactured for specific performance
  Ex: - To power a tourch.
  To start a car engine
  To supply emergency power to a hospital.

Note:

Basic components of a Battery: -

A battery is made up of anode and cathode which are surrounded by their electrolytes. The anode and cathode are separated by separator. The outer surface of the battery is covered by plastic layer and in modern batteries the ventilator are also provided to escape the accumulated gases during the process.

A battery consists of four major components.



1. **Anode: -** In a battery anode is a negative e^{-de}. It releases electrons into the external circuit by undergoing oxidation reaction. In rechargeable battery it acts as positive terminal (cathode) during charging. It gives the electrons to the external circuit.

$$M_{(S)} \longrightarrow M^{n+}_{(aq)} + ne^-$$

Zinc, Lithium, Nickel, Cadmium, and Lead are extensively used as anodes and of these Lithium tops, the list because it readily gives off electrons. (Reduction potential is highest. (-3.05V)).

2. **Cathode: -** In a battery cathode is a positive e^{-de}. It accepts the electrons from the external circuit. There by reduction of the active species occurs. In rechargeable battery it acts as negative terminal (anode) during charging.

$$M^{n+}_{(aq)} + ne^- \longrightarrow M_{(S)}$$

Graphite rod, Zinc, Lead, Nickel and Cadmium are used as cathodes. Sometimes both anode and cathode are made up of same material like lead as in the case of lead-acid battery.

3. **Electrolyte: -** It provides the medium for transfer of ions inside the cell b/w the anode and cathode. A solution of an acid, alkali (or) salt having high ionic conductivity is commonly used as an electrolyte.
4. **Separator: -** It is used to separate anode and cathode compartments in a battery to prevent internal short circuiting. The main function of the separator is to transport ions from anode to cathode and vice versa. It is highly resistance towards electrolyte.

Ex: - Cellulose, vinyl polymer, polyolifine membranes etc.…

In addition, cathode & anode current collector, terminals, seal and container make a battery complete.

Classification of Batteries:-

Batteries are classified as, **1.** Primary Batteries (Non-rechargeable Batteries)

2. Secondary Batteries (Rechargeable Batteries)

3. Reserve Batteries.

1. Primary Battery: -

The batteries which produce electrical energy at the expense of free energy of active materials and produce energy only as long as active materials are present.

(OR)

The battery which cannot be recharged and discarded when the battery has delivered all its electrical energy is called as a primary battery.

Ex: - Zn-Mno_2 battery, Li-Mno_2 battery, etc,….

In these batteries, the reaction is spontaneous but irreversible. These batteries have a higher capacity and initial voltage than rechargeable batteries.

2. Secondary Battery: -

The batteries which produce electrical energy at the expense of free energy of active materials. These active materials are capable of restoring at respective electrodes on recharge and prepare for discharge once again. These are rechargeable batteries and can be used again and again.

(OR)

A battery which after discharge, can be charged again by passing the electric current through it in the opposite direction to that of the discharge is known as secondary battery.

Ex: - Lead-Acid battery, Nickel-Cadmium battery, etc…..

In these batteries the reaction is reversible.

3. Reserve Battery: -

These are batteries which may be stored in inactive state and are made activated just before they are needed. The activation involving by adding electrolyte because one component of the electrolyte is isolated and stored separately when the battery is required.

Ex: - Mg-H_2O activated battery, Zn-Ag_2O battery, Li-V_2O_5 battery etc…….

Li – ion Battery: -

The batteries in which lithium ions are used instead of lithium metal and movement of lithium ion through electrolyte takes place from one electrode to another electrode, such batteries ae called Lithium – ion batteries.

Ex: Li – Polymer Battery, Li Cobalt oxide Battery, etc,

Construction and working of $LiCoO_2$ Battery: -

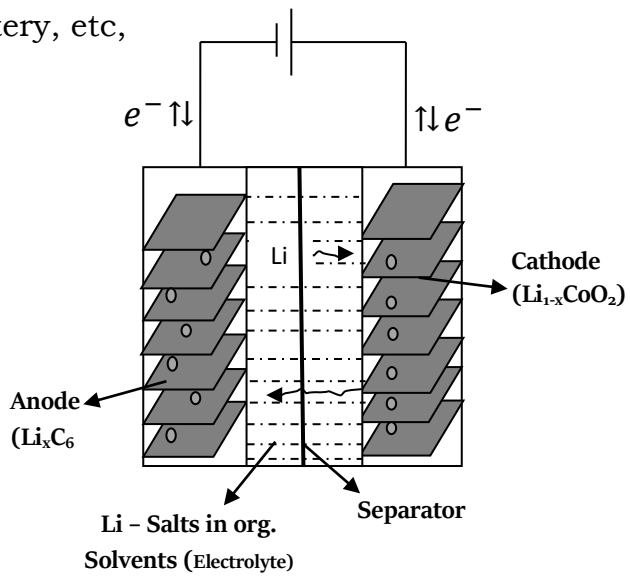
Construction: -

Anode: Lithium Carbon Material (Li_xC_6)

Cathode: Lithium Cobalt Oxide ($Li_{1-x}CoO_2$)

Electrolyte: Lithium Salts Dissolved in Organic Solvents.

Separator: Polyethylene or Polypropylene



Working: -

During discharging of battery

Lithium atoms from hard carbon material are oxidized, liberating electrons and Lithium ions. Electrons flow through external circuit to cathode and Lithium ions flow through the organic electrolyte towards cathode.

At cathode, Lithium ions are reduced to Lithium atoms and are inserted in to the layered structure of metal oxide.

During charging of battery

Lithium atom present in the layered structure of metal oxide are oxidized, liberating electrons and Lithium ions. Electrons flow through external circuit and Lithium ions flow through the electrolyte towards carbon electrode.

At carbon electrode, Lithium ions are reduced to Lithium atoms and are inserted in to the layered structure of carbon electrode.

Anode: $LiC_6 \underset{Recharging}{\overset{Discharging}{\rightleftharpoons}} Li^+ + 6C + e^-$

Cathode: $CoO_2 + Li^+ + e^- \underset{Recharging}{\overset{Discharging}{\rightleftharpoons}} LiCoO_2$

Overall reaction: $LiC_6 + CoO_2 \underset{Recharging}{\overset{Discharging}{\rightleftharpoons}} LiCoO_2 + 6C$

Applications: -

- Mobile devices
- Radio controlled aircraft
- Electric vehicles, Digital Camera
- Fertilizer and Fish feeding devices
- Blood pressure devices, Blood sugar indicators, Insulin pump etc.,

Na-ion battery:

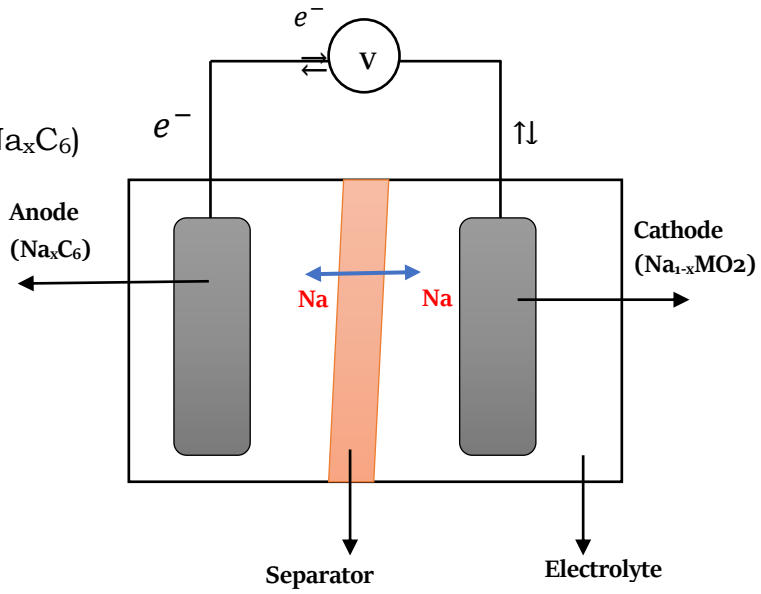
Construction: -

Anode: Sodium Hard Carbon Material (Na_xC_6)

Cathode: Sodium Layered Transition Metal Oxides ($Na_{1-x}MO_2$)

Electrolyte: Sodium Salts ($NaPF_6$) Dissolved in Polar Organic Solvents

Separator: Porous Separator



Working:

During discharging of battery

Sodium atoms from hard carbon material are oxidized, liberating electrons and sodium ions. Electrons flow through external circuit to cathode and sodium ions flow through the organic electrolyte towards cathode.

At cathode, sodium ions are reduced to sodium atoms and are inserted in to the layered structure of metal oxide.

During charging of battery

Sodium atom present in the layered structure of metal oxide are oxidized, liberating electrons and sodium ions. Electrons flow through external circuit and sodium ions flow through the electrolyte towards carbon electrode.

At carbon electrode, sodium ions are reduced to sodium atoms and are inserted in to the layered structure of carbon electrode.

$$\textbf{Anode Reaction : } Na_xC_6 \longrightarrow Na_x^+ + 6C + 6e^-$$

$$\textbf{Cathode Reaction : } Na_{1-x}MO_2 + Na_x^+ + 6e^- \longrightarrow NaMO_2$$

$$\textbf{Net Reaction : } Na_xC_6 + Na_{1-x}MO_2 \underset{R}{\overset{D}{\rightleftharpoons}} NaMO_2 + 6C$$

Applications:

- Electric vehicles
- Energy storage systems for solar, wind
- Power backup in electric utilities
- Portable LCD TV, CD player

Quantum Dot Sensitized Solar Cells (QDSSC's):-

Introduction:-

Quantum dot solar cell (QDSC) is a solar cell design that uses quantum dots as the light absorbing photovoltaic material. (Or)

Quantum dots are the small semiconductor nanoparticles with dimensions of nanometer.

Ex: - Cadmium Selenide (CdSe), Cadmium Sulfide (CdS), Lead Sulfide (PbS), Zinc Sulphide (ZnS), etc.,

In Quantum dots, the electrons and holes are confirmed in all three dimensions, leading to discrete energy levels.

Construction and Working of Quantum Dot Sensitized Solar Cells (QDSSC's):-

These are the type of Photovoltaic cells that uses Quantum dots as the light absorbing material.

Construction: -

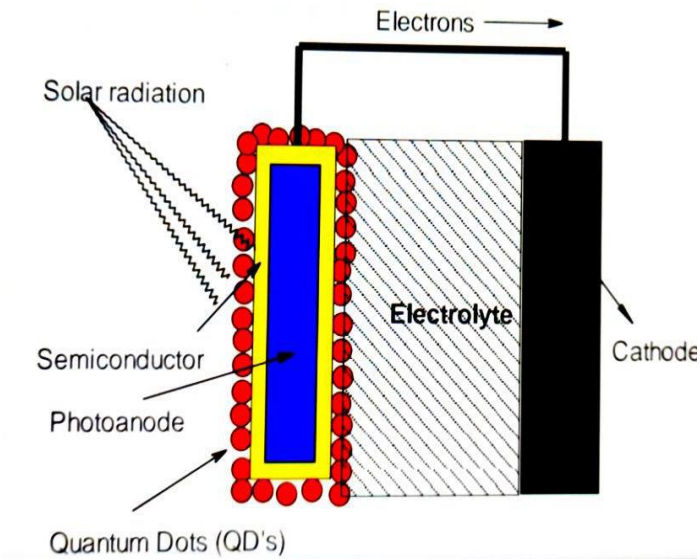
A QDSSCs consists of

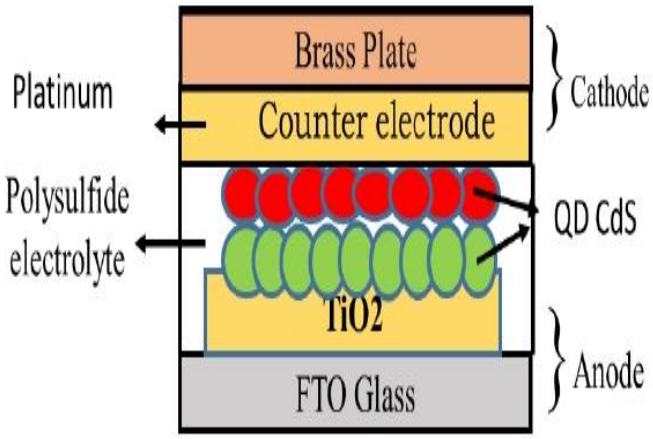
1. Photo anode: It is working electrode in the cell, over which a wide band gap semiconductor like TiO_2, ZnO etc., is coated with thickness of 10 mm. Outer layer of photoanode is coated with sensitizer quantum dots (QDs).

Sensitizer: Sensitizer is a Quantum dot it is a nanocrystal semiconductor. The QDs are typically made of semiconductor materials such as cadmium sulfide (CdS), cadmium selenide (CdSe), or lead sulfide (PbS).

2. Electrolyte: Poly sulphide redox couple is most commonly used electrolyte. It is hole conductor which can effectively take up the holes from QDs.

3. Cathode electrode(CE): This layer is made up of a conductive material, such as platinum and carbon based materials are coated on a brass substrate and serves as the top electrode. Counter electrode is acting as cathode, and it transfers electrons from external circuit to electrolyte and catalyze the reduction reaction of the oxidized electrolyte at the electrolyte/counter electrode interface (completes the circuit).





Principle: QDSSCs work based on the principle of the photovoltaic effect, which is the generation of electrical energy from light. The QDs used here are semiconducting materials that absorb light energy and generate electrons, which are then collected to produce an electric current.

Working: -

- Upon absorption of photon a quantum dot excited from ground state to higher energy state.

Excitation: $QDs + h\nu \longrightarrow QDs^*$

- The absorption process results in creation of electron – hole pair.

Electron hole – pair formation: $QDs^* \rightarrow QDs\ (e^{-*} + h^{+*})$

- The excited electron injected to conduction band of TiO2 semiconductor leaving holes on the surface of quantum dots.

Injection process: $QDs\ (e^{-*} + h^{+*}) + TiO_2 \longrightarrow TiO_2\ (e^{-*}) + QDs\ (h^{+*})$

- Injected electrons transported between the TiO2 nano particles and then it moves to photoanode, from photoanode it moves to cathode electrode (CE) through external circuit by generating electricity.

$$\textbf{\textit{Energy generation: }} TiO_2\ (e{-}*) + CE \longrightarrow TiO_2 + CE\ (e{-}*) + \textit{Electrical energy}$$

- Holes will be taken up by electrolyte and it gets reduced and regenerate.

Properties: -

- **High efficiency:** QDSSCs can achieve high conversion efficiencies due to their ability to absorb a broader range of the solar spectrum compared to conventional solar cells.
- **Size tenability**: The optical and electronic properties of QDs can be tuned by adjusting their size, making them highly versatile for use in various applications.
- **Low cost:** QDSSCs are relatively low-cost to produce compared to other types of solar cells, which makes them attractive for large-scale commercialization.

Applications: -

- **Portable devices:** QDSSCs can be used to power portable electronic devices.
- **Building-integrated photovoltaic's (BIPV):** QDSSCs can be integrated into the windows and walls of buildings to generate electricity.
- **Military applications:** Due to their light weight, flexibility, and ability to operate in low-light conditions.
- **Space applications:** QDSSCs could be used to power space vehicles and satellites