Electrical & Electronics Engineering Stream
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From : L2M Team

MODULE 2:
Energy conversion and storage

Batteries: Introduction, classification of batteries, components, construction, working and applications of modern batteries: Na-ion battery, solid state battery (Li-polymer battery) and flow battery (Vanadium redox flow battery). Fuel cells: Introduction, construction, working and applications of methanol–oxygen and polymer electrolyte fuel cell. Solar energy: Introduction, importance of solar PV cell, construction and working solar PV cell, advantages and disadvantages.

Energy conversion and storage

Introduction

1. Conversion of chemical energy into electrical energy is the function involved in cells. One of galvanic cells that convert chemical energy into electrical energy.

2. In general battery is a combination of galvanic cells neither in series (or) parallel both in order to get the required amount of electrical energy.

3. Battery is a device which transforms chemical energy of a redox reaction into electrical energy.

4. The conversion of chemical energy into electrical energy is the basis for the functioning of galvanic cell.

5. Battery is a device that's consists of two or more galvanic cells connected in series or parallel or both which converts chemical energy into electrical energy through redox reactions. Example: Zn-Air battery, lead acid battery, lithium batteries, etc.

Basic components of a battery

A battery consists of four major components. They are anode, cathode, electrolyte and separator.

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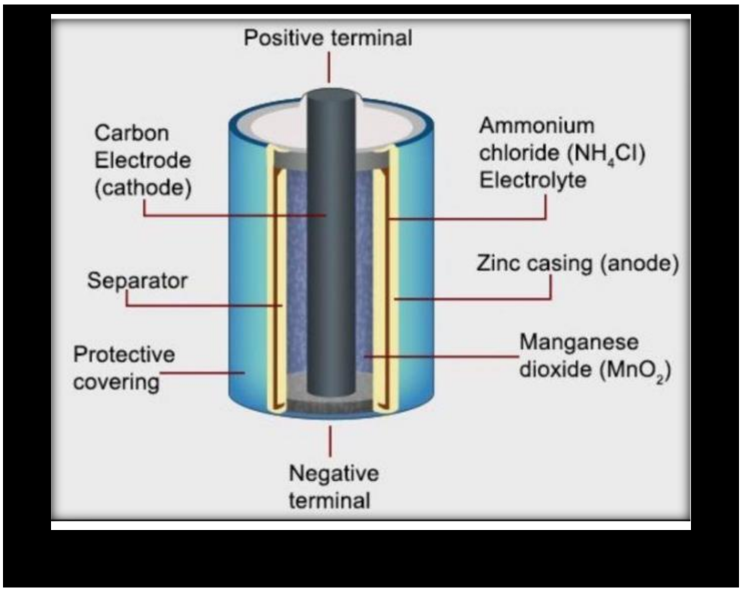


Diagram 7. Structure of a battery

- **Anode:**
  The anode (-ve electrode) is oxidized during the electrochemical reaction and liberates electrons of the external circuit.
  $M \rightarrow M^{n+} + e^-$
  Metal
- **Cathode:**
  The cathode (Positive electrode) is reduced during the electrochemical reaction which accepts electrons from external circuit.
- **Electrolyte:**
  The electrolyte which provide the medium for transfer of ions inside the cell between the anode and cathode. The electrolyte must have good ionic conductivity and resistance to the electrode materials.
- **Separator:**
  The separator: the material that electronically isolates the anode and the cathode in a battery to prevent internal short-circuiting.
  Example: Cellulose, Vinyl polymer, Polyolefins Classification of batteries

Batteries are classified

- Primary batteries
- Secondary batteries
- Reserve batteries

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

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.

Reserve Batteries

1. These batteries one of the components is isolated and incorporated into the battery when required.

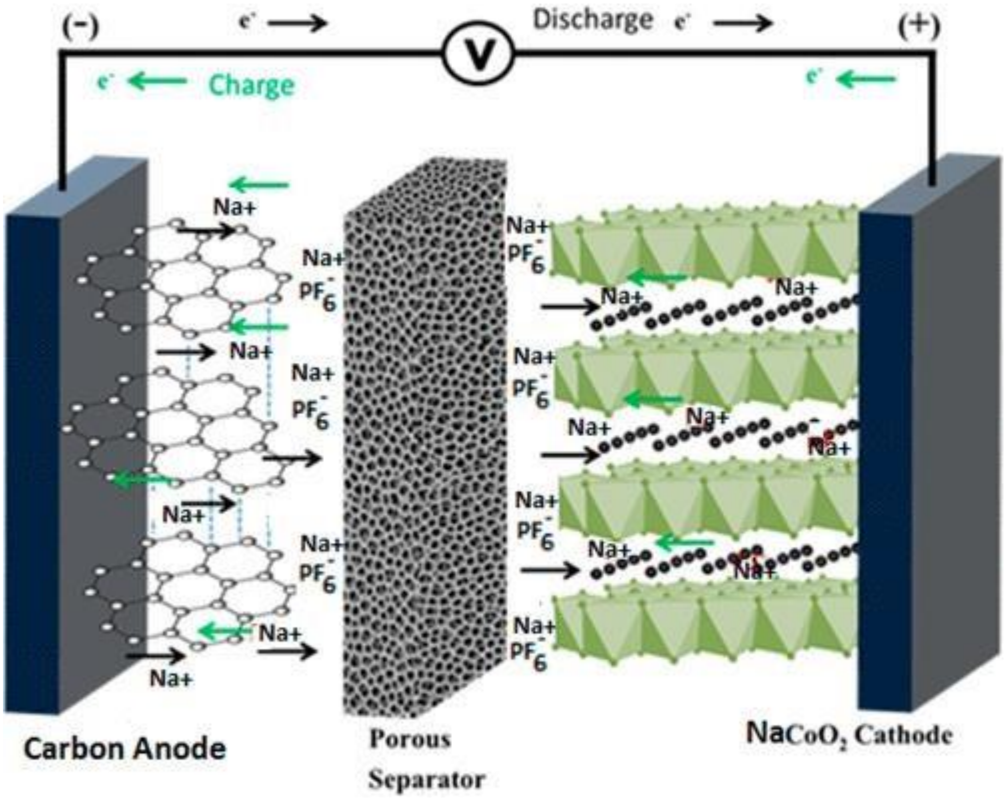
2. The electrolyte is the component that is isolated, but some water activated batteries contain the electrolyte solute and water is added for activation.

3. They are used to deliver high power for relatively short periods of time in application such as radiosondes (air borne instruments to send to meteorological information back to earth by radio).Examples: Mg batteries activated by water (Mg-AgCl, Mg-CuCl), Zn-Ag_2O batteries etc

Sodium ion Battery

- The chemistry and electrochemistry of electrode materials for Na-ion batteries are sufficiently different from that of their Li-ion counterparts that candidates suitable for practical batteries have become available only recently.

- [Figure 1](#) displays the schematic of a Na-ion battery cell.



- Cells have been built and evaluated with hard-carbon anodes and cathode materials selected from layered transition metal oxides.

- Transition metal fluorophosphates (electrolyte), and Prussian blue and its analogues are dissolved Propylene carbonate (PC): Ethylene carbonate (EC) mixed solvents are the preferred choice in the voltage window of electrolytes for sodium-ion batteries.

- Layered transition metal dioxides, $NaMO_2$, where M = Fe, Ni, Mn, Co etc.,

- The electrode reactions in a Na-ion battery utilizing hard-carbon (C_6) anode and a layered transition metal oxide, $NaMO_2$, cathode are depicted The discharged electrodes are on the right-hand side

$$Na_xC_6 + Na_{1-x}MO_2 \rightleftarrows NaMO_2 + C_6$$

- The $NaCoO_2$ cathode is initially brought into the Na-ion cell in the discharged state, and the cell is activated by charging first to form the Na intercalated anode and Na deintercalated cathode in the fully charged cell.
- They reflect the multiple phase changes of the $NaCoO_2$ crystals as Na is deintercalated from it to form $Na_{1-x}CoO_2$ during charge, and vice versa during discharge.

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.

Dis advantages of sodium ion battery.

- Large ionic size 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.
- Need high temperature for optimal work.

Solid state battery (Li-polymer battery)

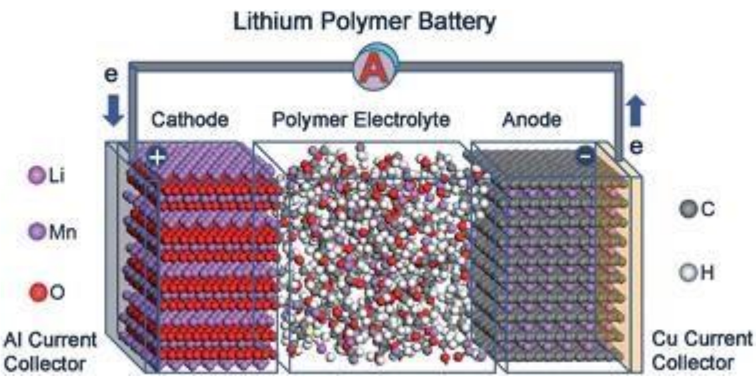
Introduction to lithium polymer battery technology

The flexibility of dimension, the high energy density and the electrical data have led to a diversity of cell design. The following designs are particularly interesting in market.

- Gel-polymer cell with improved cell cycle stability
- High energy cells with charging voltage of 4.35/4.4V
- High temperature cells for (intermittent)use up to 80^0C
- Low temperature cells that can be discharged at temperature down to 40 ^{0}

Working principle

- The principle of operation and construction of Li-polymer batteries are identical to those of Li-ion batteries.
- These batteries operate on the principle of de-intercalation and intercalation of lithium ions from positive electrode materials to negative electrode materials Electrode set:
- In Li-polymer batteries the electrode set comprises a carbon-based substance (graphite+additives) pasted onto a metallic substrate.
- The cathode consists of three-dimensional, lithiated cobalt oxides or nickel/manganese/cobalt (NMC) mixed oxides, also pasted into a metallic substrate.



Electrode reaction

Anode reaction: $Li_xC_n \rightarrow C_n + L_i^+ + Xe^-$

Cathode reaction: $Li_{1-x}MO_2 + Xe^- + XLi^+ \rightarrow LiMO_2$

Over all reaction

$Li_{1-x}MO_2 + Li_xC_n \rightarrow LiMO_2 + C_n$

Advantages of solid state battery

Solid-state batteries promise advantage given below.

(a) Greater energy density,

(b) A longer life and

(c) The greater safety,

(d) All in a smaller size.

(e) Fast charging is possible.

Disadvantages of Solid-State Battery

1. The mass production and manufacturing of solid-state batteries are quite complex.

2. Research regarding solid-state batteries is still in progress and the perfect material for the electrolyte with an ideal ionic conductivity is yet to be found.

Application of Solid-State Battery

1. Solid-state batteries are highly used in medical devices such as pacemakers, defibrillators, etc.

2. A number of gardening tools and equipment such as a lawnmower, etc., make use of solid-state batteries.

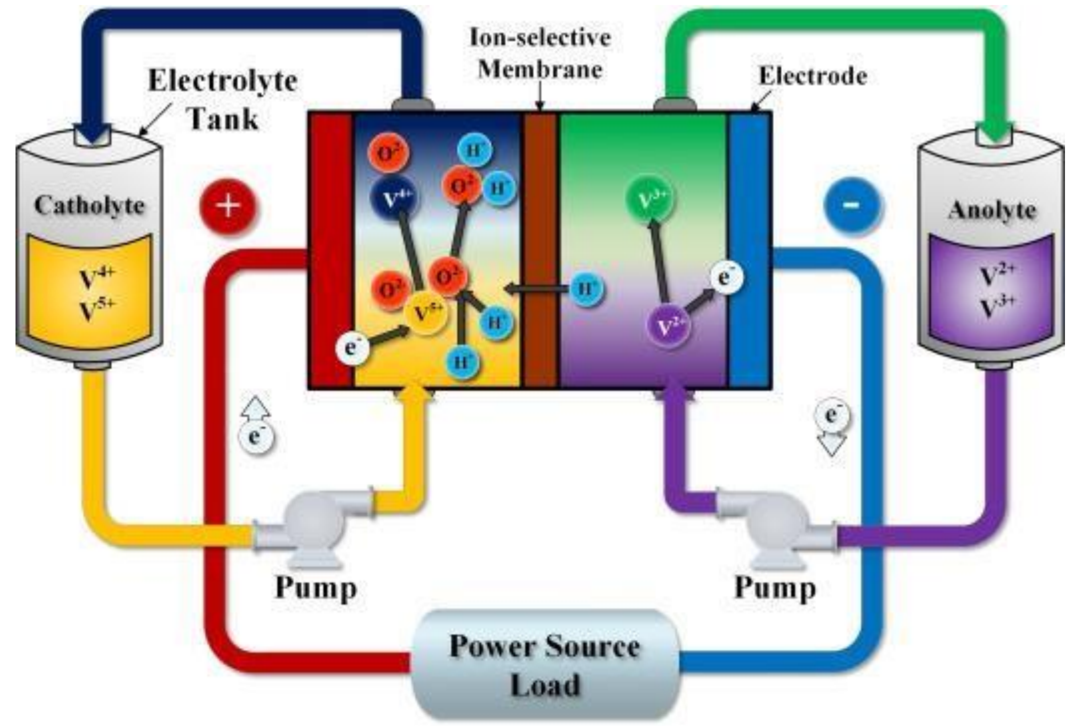
3. Automobile industry employs solid-state batteries at a large scale to power various electric vehicles.

Flow battery (Vanadium redox flow battery).

The fundamentals of an all-vanadium RFB

(a) In an all-vanadium RFB (VRFB) system, vanadyl sulphate in sulphuric acid solution is employed as initial electrolyte at both sides. The same element at different oxidation states can be converted to one another at the electrodes.

Figure shows a basic schematic of VRFBs.



Electrode reaction

(b) At the positive electrode, V(IV)/V(V) redox couple are generally VO^{2+} and $VO_{2\,-}$:

$VO^{2+}+H_2O^{-}-e^{-}\rightarrow VO_2^{+}+2H^{+}$ (charging)

$VO_2^{+}+2H^{+}+e^{-}\rightarrow VO^{2+}+H_2O$ (discharging)

E^0 = + 1.00 V versus SHE

At the negative electrode, V(II)/V(III) redox couples are either the vanadium(II) ion or the vanadium(III) ion:

$V^{3+}+e^{-}\rightarrow V^{2+}$chargeand$V^{2+}-e^{-}\rightarrow V^{3+}$ (discharge)

E^0 = − 0.26 V versus SHE

(c) The standard open circuit potential of all-vanadium systems is 1.26 V, but the practical open circuit potential depends on the operation temperature, the concentration of active species, and the state of charge. Usually, sulphuric acid is employed as the supporting electrolyte, and hydrogen ions maintain the current by passing through the membrane.

(d) Due to relatively fast kinetics and high reversibility of these two vanadium redox reactions, a high coulombic and voltage efficiency at a large current density can be expected.

(e) A VRFB can be overcharged and over discharged within the limits of the capacity of electrolytes, and it also eliminates the gassing issue during the rapidly charging cycles.

What are the advantages and disadvantages of redox flow batteries?

- Independently scalable performance and storage capacity.
- High efficiency (70 -90%)
- Long life (approximately 20 years) and unlimited number of cycles.
- Resistant to deep discharge, low self-discharge.
- Fast reactivity.
- Electrolyte not flammable or explosive.

Vanadium Redox Flow Batteries work with sustainable energy applications

(a) including Utility/Micro-grid,

(b) Commercial & Industrial, Electric Vehicle charging,

(c) Telecommunications, Off-Grid Solutions,

(d) Solar, Wind and Residential.

Fuel cells: Introduction, construction, working and applications of methanol–oxygen

FUEL CELLS

Introduction:

1. The electrochemical conversion of the free energy change of redox reaction into electrical energy is working principle of any type of cell.
2. The electrode reaction of primary batteries is irreversible and the cell produces EMF as long as the active materials are present in the cell.
3. Secondary batteries are reversible. It can be changed to give EMF.
4. 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.
5. 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.

How fuels cells are different from batteries

Conventional Batteries	Fuels cells
1.Batteries are energy storage device	1.Fuel cells are energy conversion devices
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. Waste product in a battery may be harmful. (Less eco-friendly)	4. Waste products in a fuel cell are harmless. (More eco-friendly.)

Fuel cells

<u>Definitions:</u>

A fuel 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.

A fuel cell may be represented as follows.

Fuel / Electrode / Electrolyte / Electrode / oxidant

In a fuel cell

<u>At anode</u>: the fuel undergo oxidation

Fuel$\rightarrow$ oxidized product + n e^- **<u>At</u>**

<u>cathode</u>: the oxidant gets reduced

Oxidant + n e^- $\rightarrow$ reduced product.

The fuel cell was invented by the British scientist Sir William Grrove in 1839.

The first commercial use of fuel came more than a century later in NASA space programs to generate power for satellite and space craft. **<u>Fuel cell advantages</u>**

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

Fuel cells limitation/ disadvantages

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

Methanol – Oxygen Fuel Cells [MOFC]

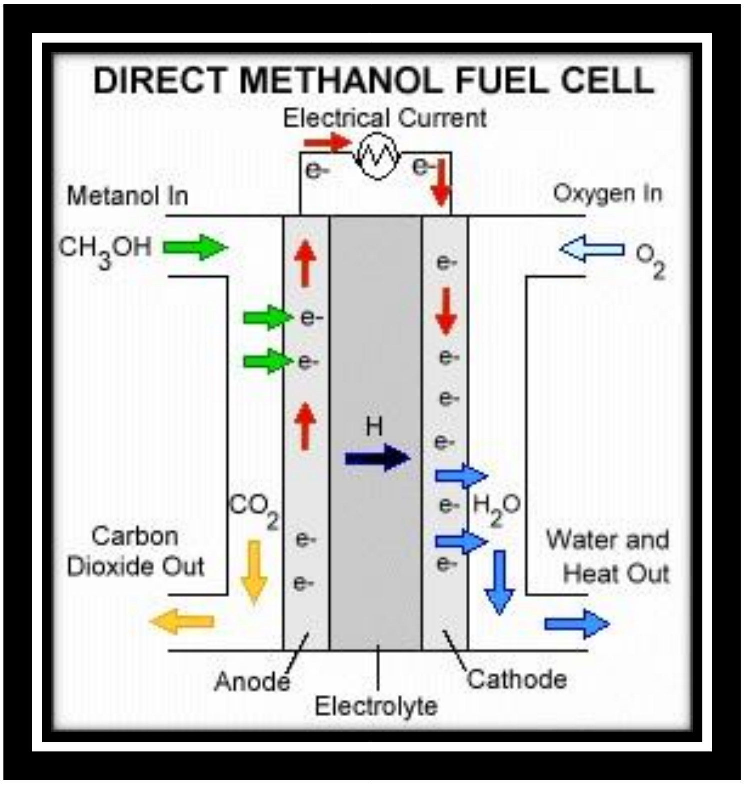


Diagram 2. MOFC

Electrode: Pt

Fuel: CH_3OH (Methanol)

Oxidant: Oxygen **Electrolyte:** H_2SO_4

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.

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

Construction

- Methanol is a Fuel and O2 is act as Oxidant.
- Both Anode & Cathode is porous Nickel sheet coated with electro catalyst.
- Pt-Pd catalyst is deposited on anode and Ag is coated on cathode.
- Methanol mixed with Water is passed through Anode chamber.
- Pure Oxygen is passed through Cathode chamber.
- To prevent the diffusion of Anode reactant Methanol into cathode chamber, a Proton conducting membrane is placed near Cathode.
- The membrane only allows Proton's [H+] to Cathode.

Working

1. The cell operates below 100^0 C.
2. In this cell both the electrodes are made of porous nickel sheets impregnated with electro-catalyst.
3. Pt-Pd catalyst is deposited on anode and silver is impregnated on cathode.
4. Methanol is circulated through the anode chamber.
5. Pure oxygen is passed through the cathode chamber. Sulphuric acid of 3.7 M is the electrolyte which is placed in the central compartment.
6. A solid ion exchange membrane methanol diffuses into the cathode and undergoes oxidation.

The cell reaction is

At anode: $CH_3OH + H_2O \ ^{-} \rightarrow \ CO_2 + 6H^+ + 6\,e^-$

(**Oxidation**)

At cathode: $1½\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

(**Reduction**)

Over all reaction: $CH_3OH + 1½\ O_2^- \rightarrow CO_2 + 2H_2O$.

Advantages of methanol-oxygen fuel cell

- Stable at all atmospheric conditioned.
- CO_2 a product of the reaction can be easily removed.
- Easy handling
- Methanol has low carbon content.
- The OH group is readily oxidized Low cost liquid fuel.

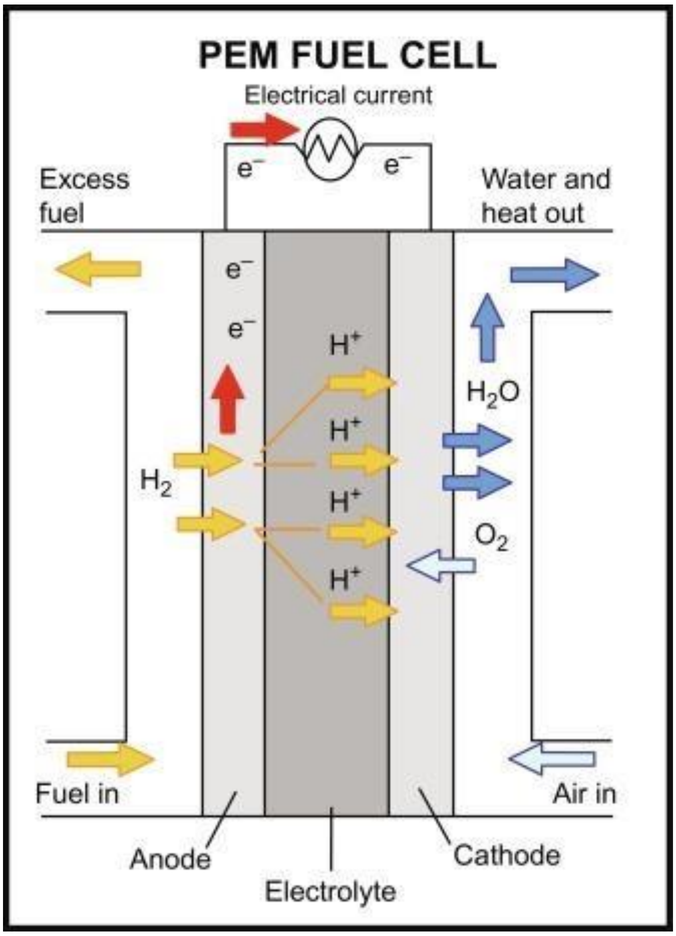
Application of methanol-oxygen fuel cell

1. The cells find application in military and large-scale power production.
2. It is also used in fuel cell vehicles and space shuttles.
3. It is ideal for powering smaller vehicles as forklift etc.

Disadvantages of methanol oxygen fuel cells

- Slow reaction.
- Requires membrane to avoid cross over from anode to cathode.

polymer electrolyte fuel cell



- It is relatively new and fast-growing technology.
- These cells operate at low temperature.
- Solid polymer membranes capable of H^+ migration used.
- Teflon-based ion-exchanger membranes containing sulphonic acid group ($-SO_3H$) are frequently used.
- The cell is compact as the membrane can be very thin.
- Porous carbon electrodes impregnated with Pt. are used as electrode.
- H_2 and O_2 are normally used as fuel and oxidant, respectively.

The cell reaction are

At the anode (oxidation): $H_2 \rightarrow 2H^+ + 2e^-$ At the

cathode (reduction): $1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$ The

overall cell reaction:

$$H_2 + 1/2O_2 \rightarrow H_2O$$

The membranes serves two important purpose

(a) Provides ionic migration

(b) Separates anodic and the Cathodic compartment so that the species do not mixed.

What are the advantages of PEFC?

The advantage of PEFC is its fast startup,

- flexibility in input fuel,
- compact design,
- lightweight,
- Low cost, and solidity of electrolyte.
- It can take pure hydrogen, methanol, as well as formic acid as input. It is ideal for portable and motile as well as stationary applications.

What are the applications of PEM fuel cell

Proton-exchange membrane fuel cells (PEMFC), also known as polymer electrolyte membrane (PEM) fuel cells, are a type of fuel cell being developed mainly for

- Transport applications, as well as for stationary fuel-cell applications and portable fuel-cell applications.

Solar energy: Introduction, importance of solar PV cell, construction and working solar PV cell, advantages and disadvantages.

Solar Energy

Photo-voltaic cells:

Photovoltaic cells or solar cells are semiconductor devices that convert sunlight into direct current. As long as light is shining on the solar cell it generates electrical power. When the light stops electricity stops.

Utilization and conversion

Solar energy utilization can be of two types

- Direct solar power.
- Indirect solar power.

Direct Solar Power

Direct solar power involves only one step transformation into a usable form.

Example 1. Photovoltaic cells: It convert solar energy to electrical energy.

Example 2. Solar Thermal collector

Sunlight hits the dark absorber surfaces of a solar thermal collector and surface warms the heat energy may be carried away by a fluid circuit

Indirect solar power

Indirect solar power involves more than one transformation to reach usable form.

Example (i) plants convert solar energy to chemical energy when they are burnt.

(ii) Fossils fuels are obtained from plants which produce heat energy that can later be burned as fuel to generate electricity.

(iii) Ocean thermal energy production uses the thermal gradient that is present across ocean depths to generate power. This temperature difference is ultimately due to the energy of the sun.

Advantages of indirect solar power

- Solar power is pollution free
- Low operating costs (no fuels)
- Facilities can operate with little maintenance Solar power is economical except the initial set up.
- High public acceptance and excellent safety record.

Disadvantages of indirect solar power

- Sunlight is a diffuse source, ie. It is relatively low-density energy.
- High installation costs.
- Energy can be produced only during the day time.

Construction and working of photovoltaic cell Construction

1. Atypical silicon photovoltaic cell is composing of a thin wafer consisting of an ultra-thin layer of Phosphorous doped (n-type) silicon on the top and boron doped (p-type) silicon at the bottom.

2. Hence a p-n junction is formed between the two.

3. A metallic grid above the diode forms one of the electrical contacts and allows the light to fall on the semiconductor.

4. The anti-reflexive layer (Silicon nitride or TiO_2) present in between the metallic grid increases the transformation of sunlight to a semiconductor. The other metallic layer at the back of the semiconductor forms another electrical contact.

Working

1. Electromagnetic radiation consists of photon. The photon carries a certain amount of energy. It is given by the Planck Constant equation is

$E=hc/\lambda$ where h is called Planck constant C is the velocity of light and λ is wavelength of the radiation.

When the electromagnetic radiation falls on the p-n junction diode, electron pair hole is generated. Electrons move and collect at the n-type end and the holes moves towards the p-type end, on connecting these two ends trough conductor flows between them to an external circuit.

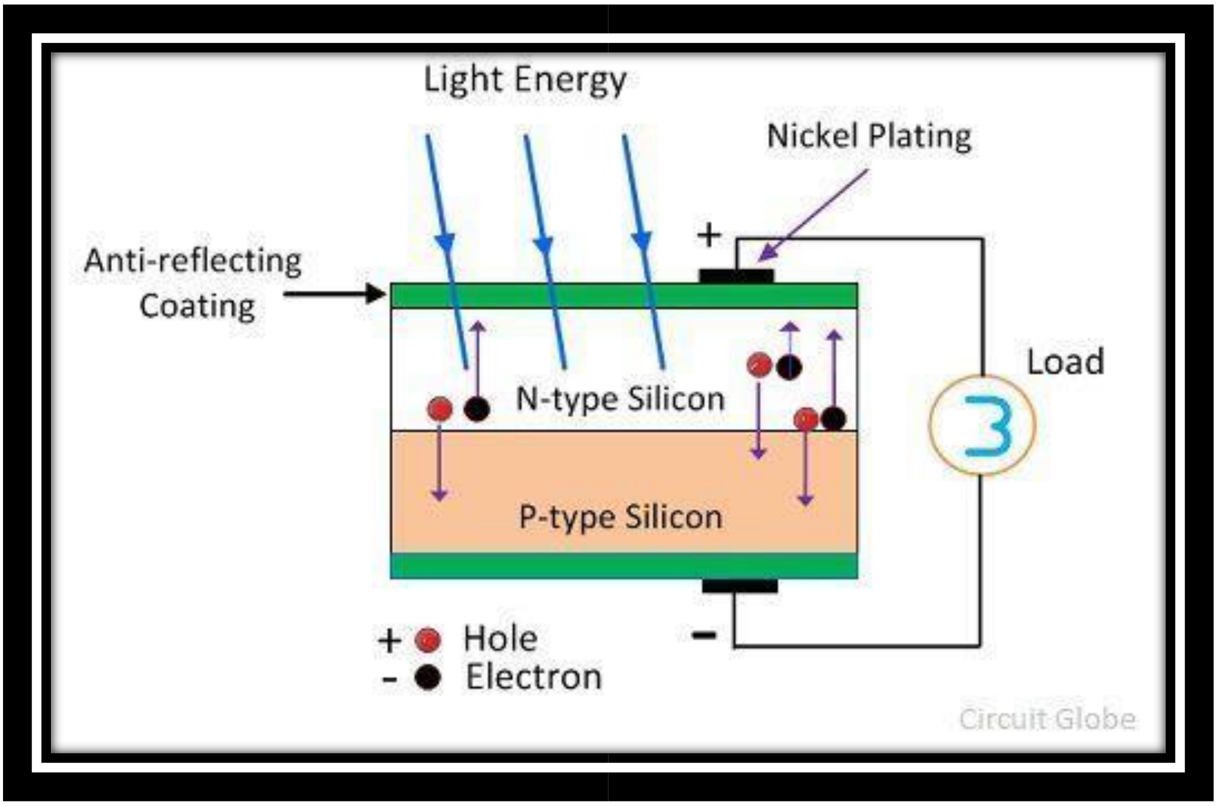


Diagram 4: PV / Solar cell

Application

1. For producing electricity using solar power plants
2. To provide electricity to satellites.
3. In remote sensing techniques from space using satellites with objectives.
4. To provide reliable weather monitoring and forecasting, there by monitoring the climatic factors.

<u>Advantages of photovoltaic systems</u>

1. <u>High reliability</u>

- Photovoltaic systems are still highly reliable even under harsh conditions. Photovoltaic arrays ensure continuous, uninterrupted operation of critical power supplies.

2. <u>Strong persistence</u>

- Most modules in a PV system have a warranty period of up to 25 years and remain operational even after many years.

3. Low maintenance costs
    - Photovoltaic systems require only regular inspections and occasional repairs, which are extremely low cost compared to conventional fuel systems.
4. Zero fuel consumption
    - Photovoltaic systems do not require fuel and can eliminate associated procurement, storage and transportation costs.
5. Noise pollution is small
    - The photovoltaic system can operate quietly with minimal mechanical movement.
6. There is photovoltaic supervision
    - In order to improve energy efficiency, photovoltaic systems may need to add some modules.
7. Strong security
    - Photovoltaic systems do not require fuel and can be safely operated after proper design and installation.
8. Strong independence
    - The reason for adopting this new technology in many residential areas is that photovoltaic systems maintain the independence of energy production and are therefore unaffected by utilities.

Disadvantages of photovoltaic systems

1. High startup cost
    - Each PV installation should be economically evaluated and compared to existing alternatives. At present, the construction cost of photovoltaic systems is relatively high, but with the reduction of photovoltaic system construction costs and the rise of traditional energy prices, photovoltaic systems will have strong economic competitiveness.
2. Available solar radiation instability
    - For any solar system, weather changes will greatly affect the amount of electrical energy output. Therefore, the system design needs to be adjusted according to changes in climate and location.
3. Have energy storage requirements
    - Some photovoltaic systems use batteries as energy storage devices. This increases the footprint, cost and complexity of the system.
4. Efficiency needs to be improved
    - In order for PV systems to reflect cost-effectiveness, we need to use an efficient method to distribute the energy generated during use.

However, they are now often used to power alternative inefficient appliances.

5. Lack of knowledge and skills
   - Photovoltaic technology is an emerging technology. The lack of relevant information limits the development of its markets and technologies.

Module -2 VTU question

1. Define batteries. Explain the construction, working and applications of Naion battery. (7 marks)
2) Explain the components in the battery? 6 marks
3) Describe construction, working and applications of Li-polymer solid state battery. (7marks)
4) Explain construction, working and applications of Vanadium redox flow battery. (7 marks)
5) Define fuel cells. Explain the construction, working and applications of Methanol-oxygen fuel cell?
6) Explain the construction, working and applications of polymer electrolyte membrane (PEM) fuel cell.
7) What are photovoltaic cells? Explain the construction and working of solar photovoltaic cell. Mention their advantages and disadvantages?
8) Explain classification battery (a) Primary batteries (b) Secondary batteries (c) Reserve batteries. (6 marks)