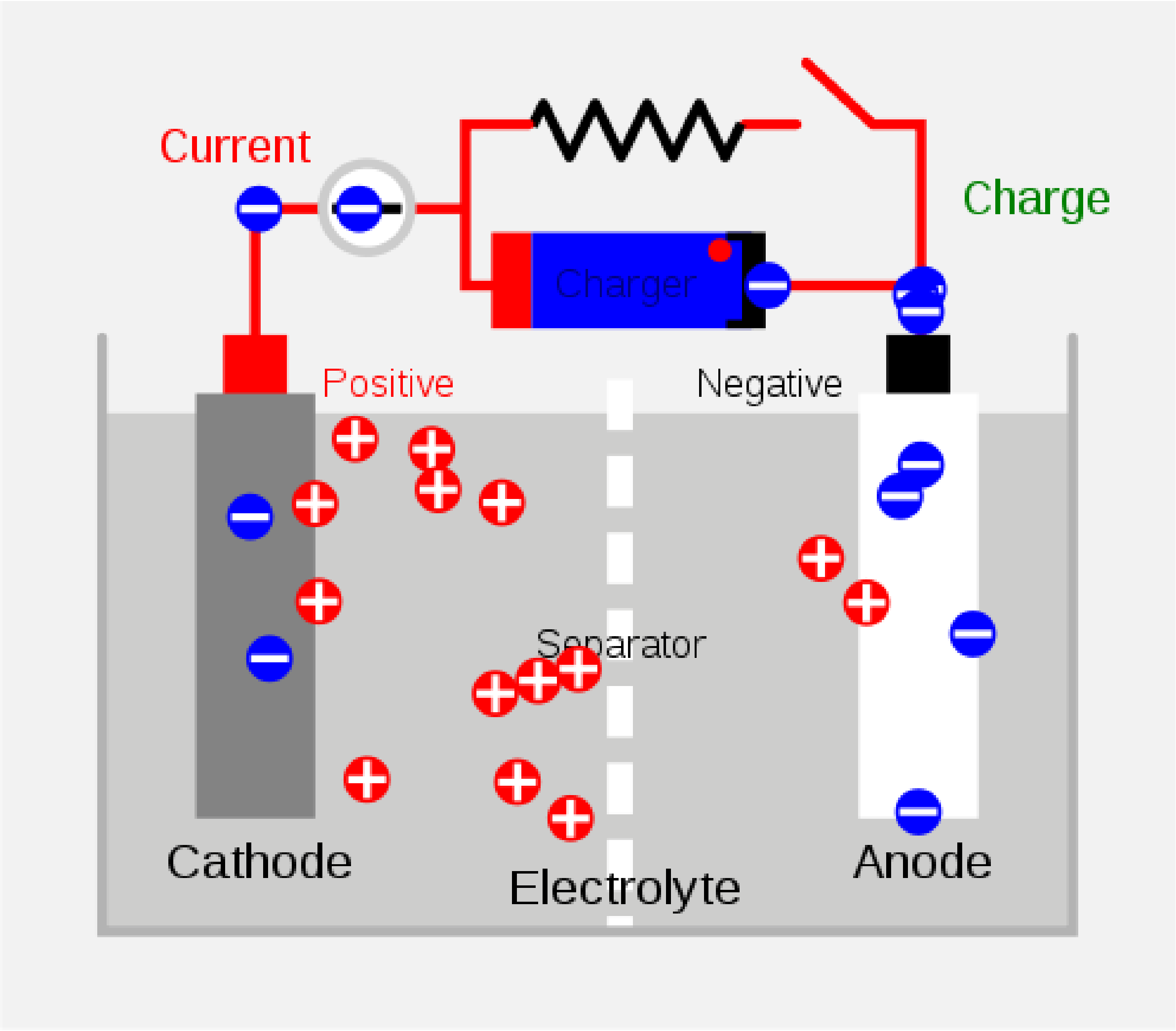
Energy Storage system

Module 1

Introduction

- The increase in the complexity and standards in life style is characterized by a high demand for energy consumption.
- In this view point cells and batteries are important in providing portable electrical energies.
- Battery technology has made possible replacement of petrol driven automobiles by electrically powdered ones.
- The variety of equipment used in diverse applications, by utilizing batteries as energy sources have spurred the development of many different types of batteries.
- The conversion of chemical energy into electrical energy is the basis for the functioning of a galvanic cell.
- A battery is a compact device consisting of two or more galvanic cells connected in a series or parallel or both. It stores chemical energy in the form of active materials and on demand converts it into electrical energy through redox reaction.

Components of a Battery



Components of a Battery

- **Components of a Battery**
  - **Anode** — It contains active materials which spontaneously take part in the oxidation reactions.
  - **Cathode** — It contains active materials which spontaneously take part in the reduction reactions.
  - **Electrolyte** — It helps in the migration of the ions leading to the generation of electrical energy.
  - **Separator** — It is a thin polymeric membrane which prevents the mixing of products formed at the electrodes.

Classification

- **Primary battery**: It is the one in which electrical energy can be obtained at the expense of chemical energy only as long as the active materials are still present. Once the active material is consumed, the cell must be discarded. Here the cell reaction are irreversible. E.g.: Leclanche Cell (Zn-MnO_2 cell).

- **Secondary Battery**: In secondary batteries the cell reactions are reversible. The discharge cell can be recharged by passing current through it in the direction opposite to that discharge current. E.g.: lead storage battery.

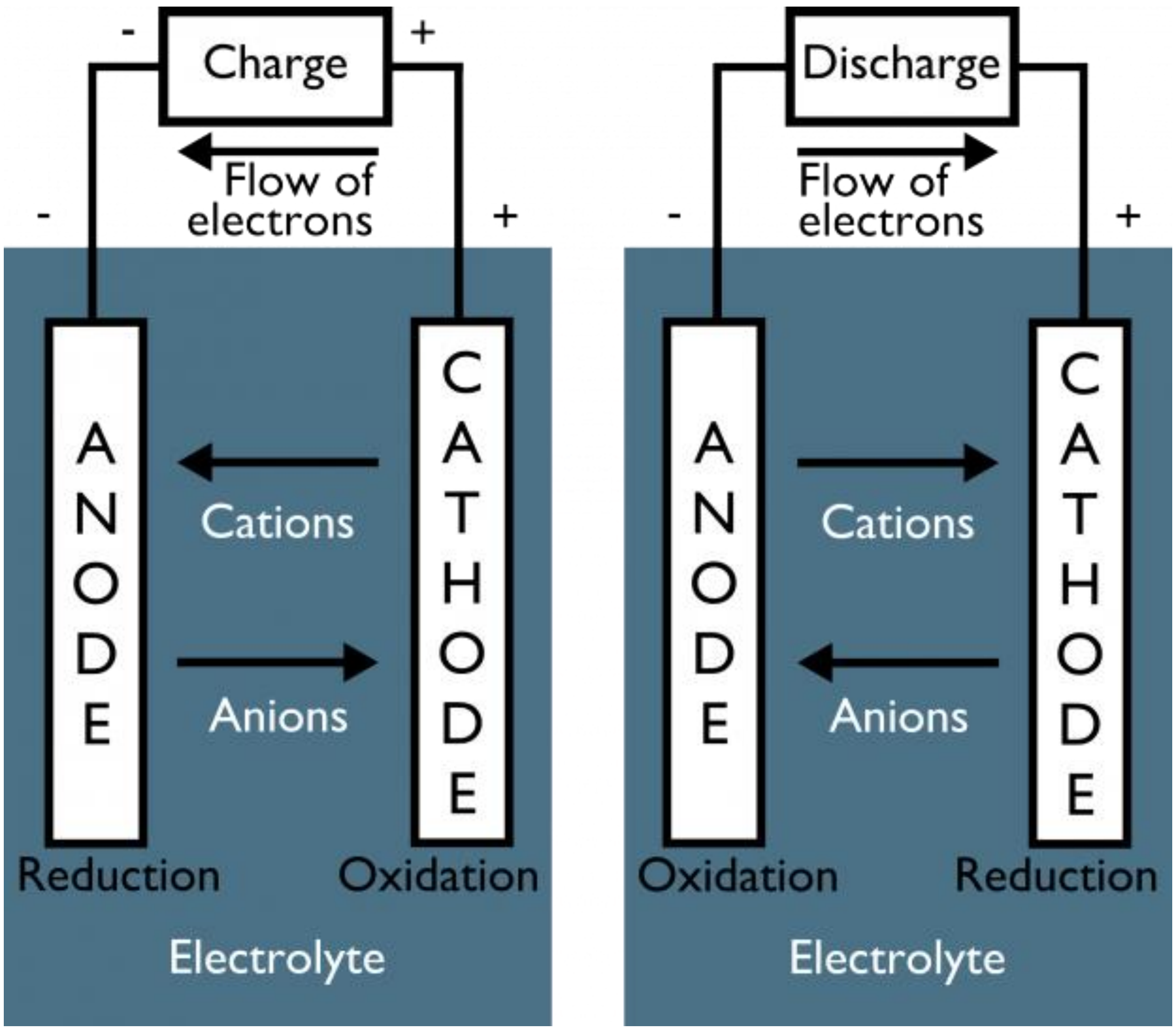
- **Reserve batteries**: Here one of the components is stored separately and is incorporated into the battery when required. Usually, the electrolyte is stored separately. E.g.: Zn – Ag_2O batteries.

Discharging and Charging of a Battery

The process in which spontaneous redox reaction occurs is called ***discharging*.**

The process of conversion of an inactive material back into active materials in a cell is called ***charging.***

Discharging and Charging of a Battery



Lithium ion battery

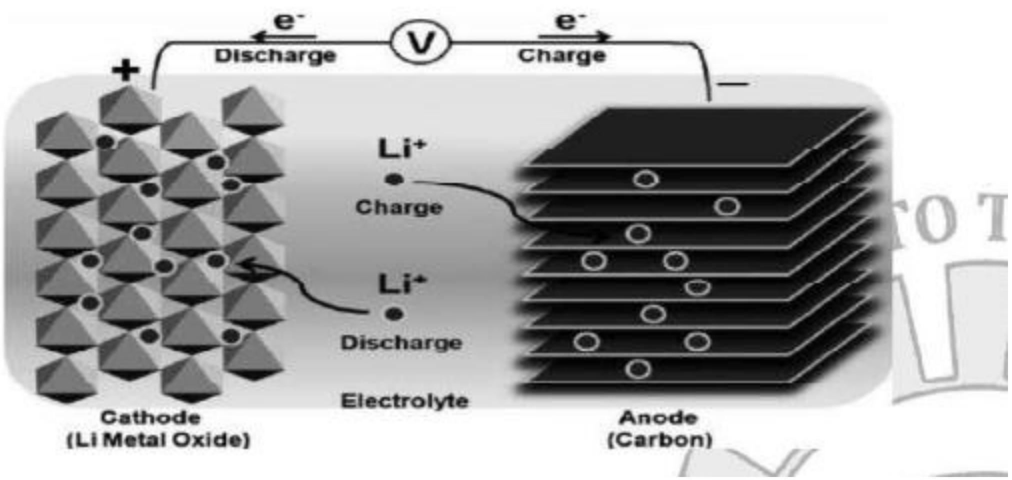
- A lithium-ion battery is a rechargeable battery type in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.
- Lithium ion batteries use an intercalated lithium compound as the electrode material, instead of metallic lithium.
- The anode is made of lithium, intercalated (reversibly included between the layers) in graphite.
- The cathode is made up from lithium liberating compounds, typically three electro-active layered oxide materials. e.g.: Lithium Cobalt-oxide ($LiCoO_2$), Lithium manganese-oxide ($LiMn_2O_4$).
- The electrolyte is a solution of lithium salt (Lithium hexafluorophosphate, lithium perchlorate, lithium tetrafluoroborate, etc.) in an organic solvent such as ethylene carbonate, dimethyl carbonate, and diethyl carbonate.

Lithium-ion battery

- The electrodes have two key properties. One is the open crystal structure, which allows the insertion or extraction of lithium ions and the second is the ability to accept compensating electrons at the same time. Such electrodes are called intercalation hosts.
- A separator is fine porous polymer film. An electrolyte is made of lithium salt in an organic solvent.
- The electrolyte provides a conductive medium for lithium ions to move between the electrodes.
- Both the electrodes allow lithium ions to move in and out of their interiors.

Lithium-ion battery

- During charging lithium in cathode electrode materials is ionized and moves from cathode to anode and gets inserted into the anode.
- During discharge Li ions are dissociated from the anode and migrate across the electrolyte and are inserted into the crystal structure of the cathode.
- At the same time the compensating electrons travel in the external cercuit and are accepted by the host to balance the reaction.
- Positive electrode: $LiCoO_2 \leftrightharpoons Li_{1-x}CoO_2 + xLi^+ + xe^-$
- Negative electrode: $xLi^+ + xe^- + xC_6 \leftrightharpoons xLiC_6$
- Overall: $LiCoO_2 + xC_6 \leftrightharpoons Li_{1-x}CoO_2 + xLiC_6$
- The forward cell reaction is charging and reversed reaction is discharging.


e-
Discharge
V
e-
Charge
+
−
Li+
Charge
Li+
Discharge
Electrolyte
Cathode
(Li Metal Oxide)
Anode
(Carbon)

Lithium-ion battery

Advantages:

- They have high energy densities than other rechargeable batteries.
- They are light weight.
- The produce high voltage out of 4 V.

Disadvantages:

- Expensive.
- Safety issues.

Application:

- They are used in portable devices (mobile phones, laptops, cameras)
- Due to light weight they are used in many electric vehicles.
- They are used in telecommunication equipment, TVs etc.

Difference between Lithium and Lithium ion battery

Lithium battery:

- It is a primary battery.
- Lithium in pure form taken as anode.
- Here intercalation occurs on only one electrode (cathode).
- It has smaller lifetime.

Lithium ion battery:

- It is secondary battery.
- $LiCoO_2$ is taken as anode.
- Here Li ions are deposited by the intercalation of compounds on both the electrodes.

Zinc-air cell

(a) Zinc – air battery is a primary battery.

(b) It is a one type of metal – air batteries, which use oxygen directly from the atmosphere to produce electrochemical energy. Air does not contribute to the mass of the battery, hence offers high energy density.

(c) **Components of cell**:

(i) Cathode: It consists of a porous carbon plate with catalyst. The catalyst layer contains carbon blended with oxides of manganese to form a conducting medium. The active material is oxygen, which is activated to undergo reduction reaction and treated with water repellants. The porous structure cathode allows air to diffuse inside and come in contact with the electrolyte.

Reaction: $\frac{1}{2} O_2 + H_2O + 2e \longrightarrow 2OH^-$

(ii) Anode: It is made up of loose, granulated powder of zinc mixed with an aqueous alkaline electrolyte (30% KOH) and a gelling agent to immobilize the composite and ensure adequate contact with zinc granules. Here Zn-metal undergoes oxidation in presence of electrolyte.

Reaction: $Zn + 2OH^- \longrightarrow ZnO + H_2O + 2e$

Overall cell reaction: $Zn + \frac{1}{2} O_2 \longrightarrow ZnO$

(iii) Electrolyte: It contains an aqueous alkaline electrolyte (30% KOH) solution.

(iv) Separator: The two electrodes are separated by an oxygen absorbing separator.

(d) The can halves housing the cathode and anode materials also act as the terminals. The two containers are provided by a plastic gasket as insulation between the two containers.

(d) During the cell reaction the electrolyte remains invariant and the air cathode act as the only reaction site and is not consumed.

(e) A very thin cathode of the cell (about 0.5 mm) permits the use of very large zinc anode. The result is higher energy density.

(f) The cell produces an open circuit potential of 1.4V.

Advantage:

(a) High energy density

(b) Long shell life

(c) Low cost

Disadvantage:

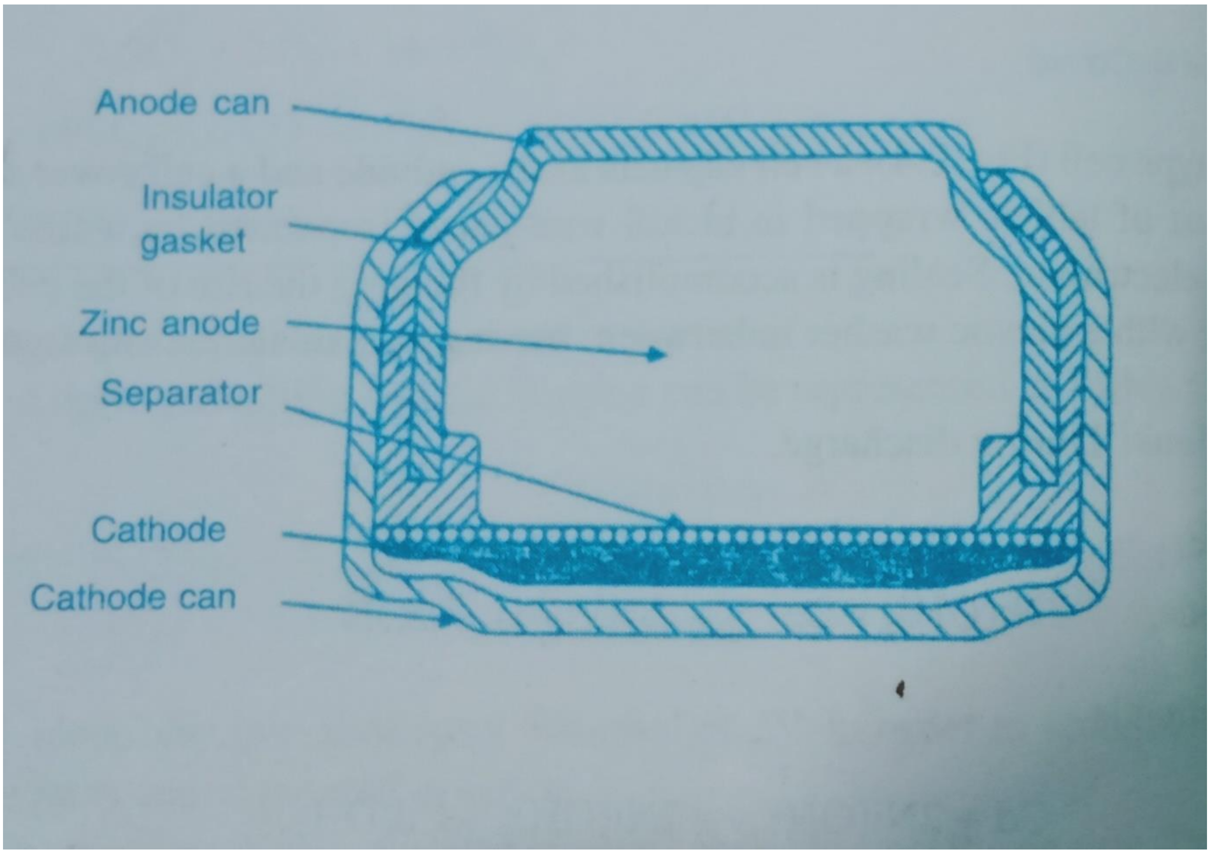
(a) Limited power output

(b) Short activated life

Application:

(a) Used in various medical devices

(b) Used as a power source for hearing aids.



Fuel cell

Definition:

It is a galvanic cell in which the chemical energy contained in a readily available fuel oxidant system is converted directly into electrical energy by means of electrochemical process.

Advantages:

• High efficiency of the energy conversion process

• The overall reaction products are not toxic to the environment and thus are eco-friendly.

• No need of charging.

Limitations:

• The production of energy is possible as long as the fuels and oxidants are supplied.

• Cost of power is high due to the use of costly electrodes.

Difference between Fuel cell and Conventional cell:

Fuel Cell	**Conventional Cell**
1. In a cell, the reactants do not form an integral part; they are fed from outside.	1. The reactants do form an integral part.
2. They do not store chemical energy.	2. They store chemical energy.
3. Reactants are constantly supplied and the products are constantly removed from the system.	3. Reactants and the obtained products are present inside the cell.
4. No charging is required.	4. Charging (secondary cell) is required.
5. Ex: H_2 - O_2 fuel cell.	5. Ex: Lead-acid battery.

$H_2 - O_2$ fuel cell

(a) It is the simplest type of fuel cell, where hydrogen gas is used as a fuel and oxygen gas is used as an oxidant.

(b) The electrodes consist of a porous carbon electrode impregnated with catalyst such as finely divided Platinum.

(c) The electrolyte is an aqueous conc. solution of KOH and the electrodes are placed in it.

(d) Anode: The supplied hydrogen gas diffuses through the porous anode and gets adsorbed on the electrode surface. In presence of electrolyte, it undergoes oxidation reaction: $H_2 + 2OH^- \longrightarrow 2\,H_2O + 2e$

(e) Cathode: The supplied hydrogen gas diffuses through the porous cathode and gets adsorbed on the electrode surface. In presence of electrolyte, it undergoes reduction reaction: $\frac{1}{2}\,O_2 + H_2O + 2e \longrightarrow 2OH^-$

Overall cell reaction: $H_2 + \frac{1}{2}\,O_2 \longrightarrow H_2O$

(f) The cell reaction is nothing but the combustion of hydrogen. It is noted that fuel cell does not store electrical energy. They are merely energy conversion device.

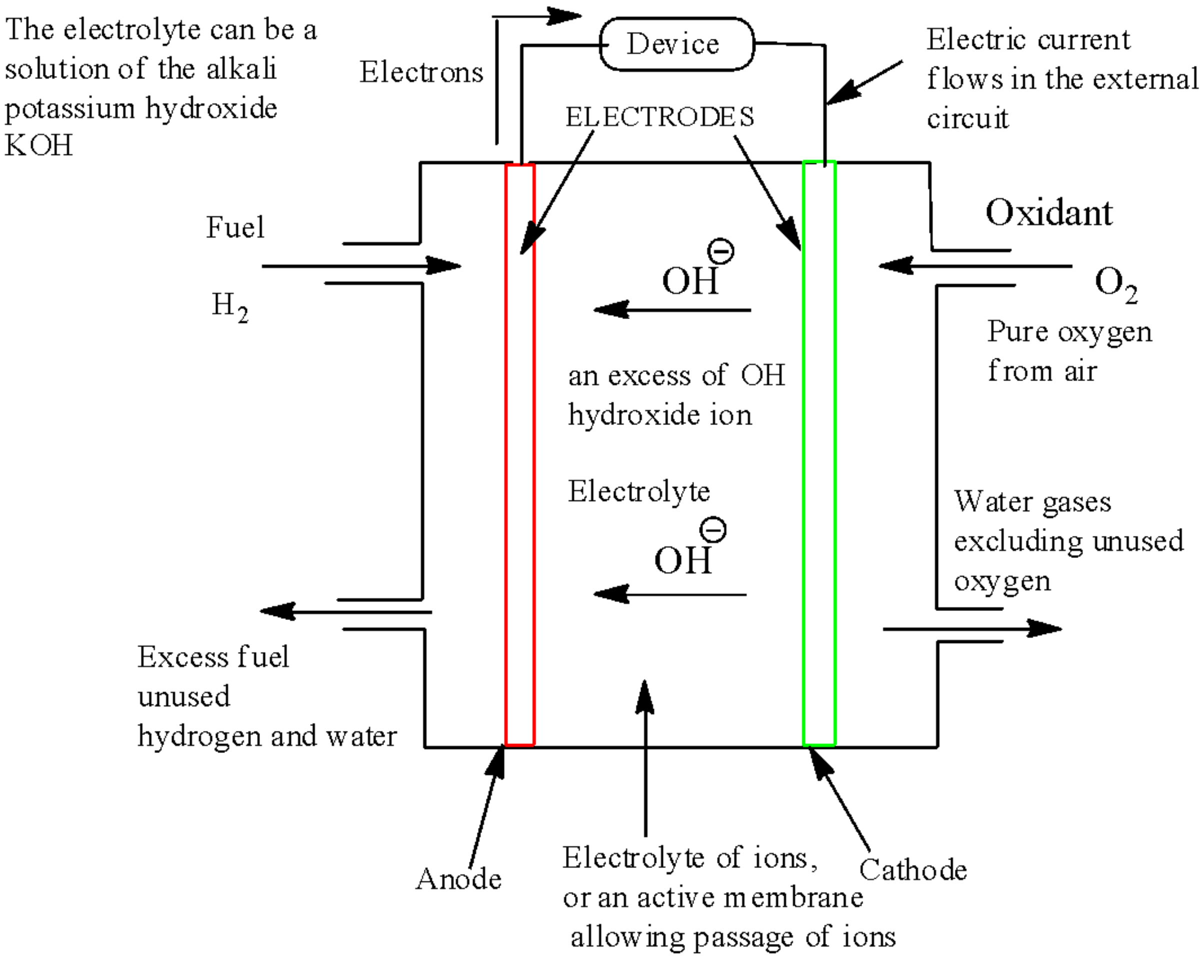
(g) The cell produces an open circuit potential of 1.23V.

(h) The electrolyte kept under hot condition, so that the generated water evaporates and come out of the system.

<u>Application</u>:

(a) Used as an electric power source for space vehicles.

(b) Also, for military applications and mobile power systems.



An alkaline hydrogen-oxygen FUEL CELL

Solid oxide fuel

- These fuel cells are best suited for large-scale stationary power generators that could provide electricity for factories or towns.
- Current operating temperature is 700-1000˚C.
- This high temperature makes reliability a problem, because parts of the fuel cell can break down after cycling on and off repeatedly.
- However, solid oxide fuel cells are very stable when in continuous use. In fact, the SOFC has demonstrated the longest operating life of any fuel cell under certain operating conditions.
- The high temperature also has an advantage: the steam produced by the fuel cell can be channeled into turbines to generate more electricity.
- This process is called co-generation of heat and power (CHP) and it improves the overall efficiency of the system.
- It consists of three components: a cathode, an anode, and an electrolyte sandwiched between the two.

Solid oxide fuel

- The electrodes are porous in nature and enable suitable condition for particular type of redox reaction in the respective electrodes.
- This electrochemical reaction generates electrons, which flow from the anode to an external load and back to the cathode, a final step that both completes the circuit and supplies electric power.
- To increase voltage output, several fuel cells are stacked together to form the heart of a clean power generator. They operate at high temperatures (1000-1500˚C) and a practical efficiency of 50-60%.
- SOFC are based on the concept of oxygen ion conducting solid electrolyte which the oxide ions migrate from the air cathode side to the fuel electrode. E.g. Yttria-stabilized zirconia. These kind of electrolytes generates oxygen ions at high temperature.

Solid oxide fuel

- The **cathode** is based porous cermet coated with on a mixed conducting perovskite, Strancium doped Lanthanum manganate. Oxygen from the air flows through the cathode. It undergoes reduction reaction to form oxide ions. Negatively charged oxide ions migrate through the electrolyte membrane and react with the hydrogen and CO to form water and CO_2.
- The **anode** is typically constructed from an electronically conducting Ni/yttria-stabilized zirconia cermets. They are porous and have high resistance capacity. Water gas containing hydrogen and Carbon mono oxide flows past the anode.

Cell reactions: ***For H_2***:

Anode: $H_2 + O^{2-} \rightarrow H_2O + 2e$

Cathode: $\frac{1}{2} O_2 \rightarrow O^{2-} + 2e$

Overall reaction: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

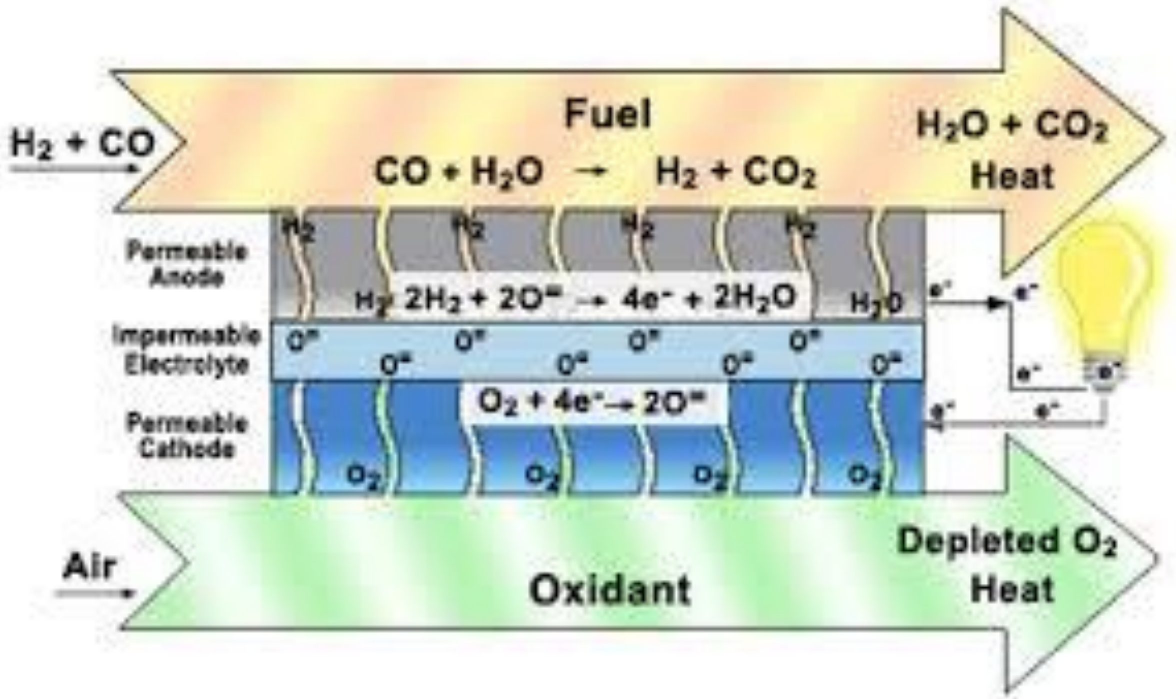
Cell reactions: ***For CO***:

Anode: $CO + O^{2-} \rightarrow CO_2 + 2e$

Cathode: $\frac{1}{2} O_2 \rightarrow O^{2-} + 2e$

Overall reaction: $CO + + \frac{1}{2} O_2 \rightarrow CO_2$

Solid oxide fuel



Application

- It is used as a power generator for residential as well as commercial purpose.
- It is used to power heavy vehicles like trucks and buses.
- The steam produced by the fuel cell can be channeled in turbine to generate more electricity.

[**Note: Yttria-stabilized zirconia** (**YSZ**) is a ceramic in which the crystal structure of zirconium dioxide is made stable at room temperature by an addition of yttrium oxide. These oxides are commonly called "zirconia" (ZrO_2) and "yttria" (Y_2O_3), hence the name.

Perovskite is a calcium titanium oxide mineral composed of calcium titanate ($Ca\ Ti\ O_3$). It lends its name to the class of compounds which have the same type of crystal structure as $CaTiO_3$ ($^{XII}A^{2+\,VI}B^{4+}X^{2-}{}_3$), known as the perovskite structure.]