Fuel cells

Fuel cells are electrochemical cells consisting of two electrodes and an electrolyte which convert the chemical energy of chemical reaction between fuel and oxidant directly into electrical energy.

❖ Ordinary Combustion process of fuel is

Fuel + Oxygen → Combustion Products + Heat

❖ The process of fuel cell is

Fuel + Oxygen → Oxidation Products + Electricity

• The conventional process to produce electrical energy is as follows:

Chemical Energy → Heat → Mechanical Energy → Electrical Energy

• But in fuel cell, it directly coverts chemical energy to electrical energy.

• The efficiency of energy conversion in fuel cell approaches 70%. It is only 15-20% in gasoline powered engines and 30 – 35% in diesel engines.

Principle of Fuel Cell:

- Fuel cell consists of electrodes, electrolyte & catalyst to facilitate the electrochemical redox reaction.
- The basic arrangement in a fuel cell can be represented as follows:

Fuel	Electrode	Electrolyte	Electrode	Oxidant

Fuel cell consist of

Anode & Cathode

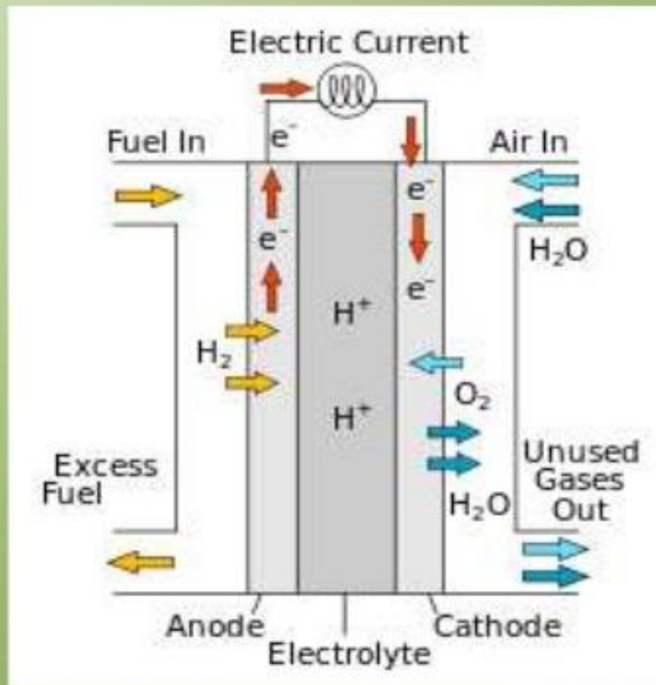
- Materials which have high electron conductivity & zero proton conductivity in the form of porous catalyst (porous catalyst or carbon).

Catalyst

- Platinum

Electrolyte

- High proton conductivity & zero electron conductivity.



➢ Fuel Cell System:

1. The fuel (direct H_2 or reformed H_2) undergoes oxidation at anode and releases electrons.

2. These electrons flow through the external circuit to the cathode.

3. At cathode, oxidant (O_2 from air) gets reduced.

4. The electrons produce electricity while passing through the external circuit. Electricity is generated continuously as long as fuel and the oxidant are continuously and separately supplied to the electrodes of the cell from reservoirs outside the electrochemical cell.

- The Fuel cell can be represented as:

At anode	• $2H_2 \rightarrow 4H^+ + 4e^-$
At Cathode	• $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Overall Reaction	• $2H_2 + O_2 \rightarrow 2H_2O$

- Large number of these cells are stacked together in series to make a battery called as fuel cell battery or fuel battery.

Advantages of Fuel Cells

1. High efficiency of energy conversion (approaching 70%) from chemical energy to electrical energy.
2. Low noise pollution & low thermal pollution.
3. Fuel cell power can reduce expensive transmission lines & minimize transmission loses for a disturbed system.
4. Fuel cells gives excellent method for efficient use of fossil fuels hence saves fossil fuels.
5. Fuel cells are less polluting. The chemical process involved in it is clean. It does not produce polluting exhaust. Mostly the byproducts are water & waste heat, which are environmentally acceptable when hydrogen & air are used as reactants.

Advantages of Fuel Cells

6. In case of fossil fuels, when used as reactants, environmentally undesirable NO_x are not produced since there is no combustion in the process.
7. Hydrogen-Oxygen fuel cells produce drinking water of potable quality.
8. Designing is modular, therefore the parts are exchangeable.
9. Low maintenance cost.
10. Fuel cell performance is independent of power plant size. The efficiency does not depend on the size of power plant. It remains same for the plants of MW or kW or W size.

Advantages of Fuel Cells

11. Fast start up time for low temperature system.
12. The heat is cogenerated hence increases efficiency of high temperature system.
13. The demand for variations in power & energy densities is easily met as required. e.g. Laptop, computers requires low power density & high energy density where as automobile requires high power density, high energy density. Both can be powered by fuel cells.
14. Fuel cells automotive batteries can render electric vehicles, efficient & refillable.

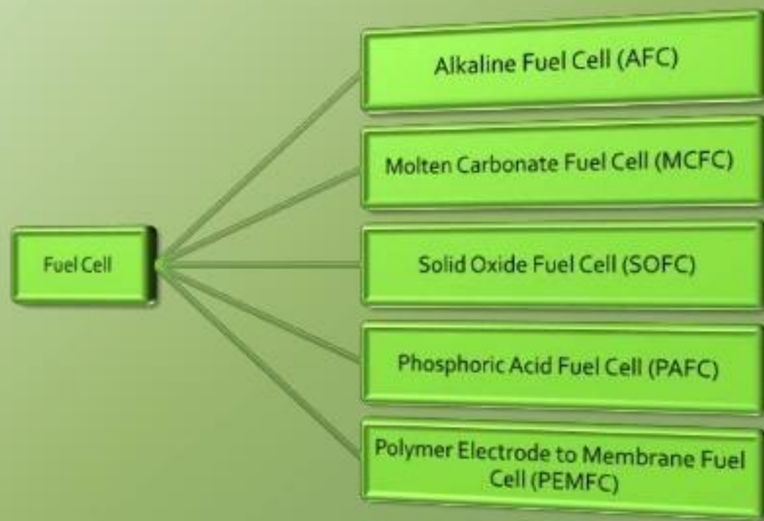
Disadvantages of Fuel Cells

- High initial cost.
- Life times of the cells are not accurately known.
- Large weight and volume of gas fuel storage system.
- High cost of pure hydrogen.
- Hydrogen can be stored in lesser volume by liquefaction but liquefaction itself require 30% of the stored energy.
- Lack of infrastructure for distributing hydrogen.

Applications of Fuel Cells

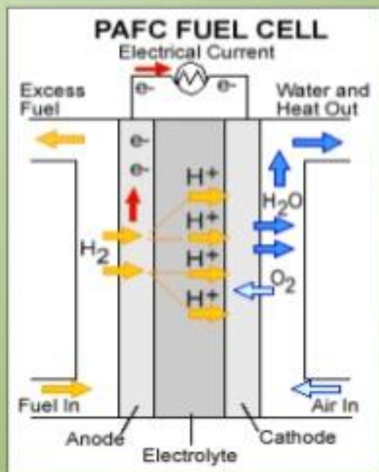
- The first commercial use of fuel cell was in NASA space program to generate power for satellites and space capsules.
- Fuels are used for primary and backup power for commercial, industrial and residential buildings in remote and inaccessible area.
- They are used to power fuel cell vehicles including automobiles, aeroplanes, boats and submarines.

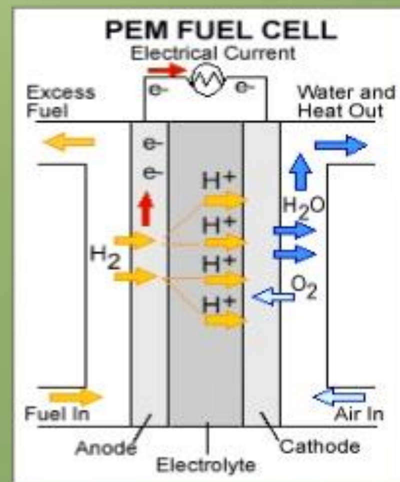
Types of Fuel Cells



Two Commercially important Fuel Cells as:

- Phosphoric Acid Fuel Cell
- Polymer Electrode to Membrane Fuel Cell





Characteristic features	PEMFC	PAFC
Primary fuel	H_2	H_2
Electrodes	Graphite	Carbon
Electrolyte	Polymer membrane(Per fluoro sulphonic acid)	Phosphoric acid soaked in silicon matrix
Catalyst	Pt	Pt
Operating temperature	50 – 100°C (typically 80°C)	150 – 200°C
Major applications	Stationary and automotive power	Stationary power
Advantages	•Solid electrolyte reduce corrosion & electrolyte management problems •Operates at low temperature •Quick start up	•Higher temperature combines heat power •Increases tolerance to fuel impurities
Disadvantages	•Expensive catalyst •Sensitive to fuel impurities	•Expensive catalyst •Long start time •Low current & power

Comparison of PAFC & PEMFC

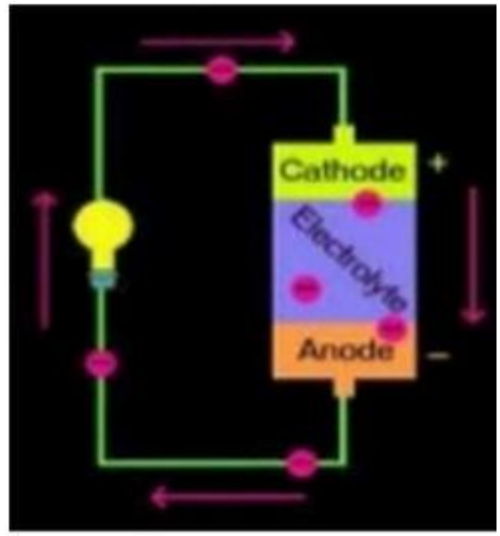
- It has H_2 as a primary fuel.
- It requires carbon as an electrode.
- Phosphoric acid is used as an electrolyte.
- Platinum acts as catalyst.
- It's operating temperature is 150 to 200°C.
- It has major applications in stationary & automotive power.

- It has H_2 as a primary fuel.
- It requires graphite as an electrode.
- Polymer membrane is used as an electrolyte.
- Platinum acts as catalyst.
- It's operating temperature is 50 to 100°C (typically 80°C).
- It has major applications in stationary power.

Applications using Batteries

Battery

- Convert stored chemical energy into electrical energy
- Reaction between chemicals take place
- Consisting of electrochemical cells
- Contains
  - Electrodes
  - Electrolyte

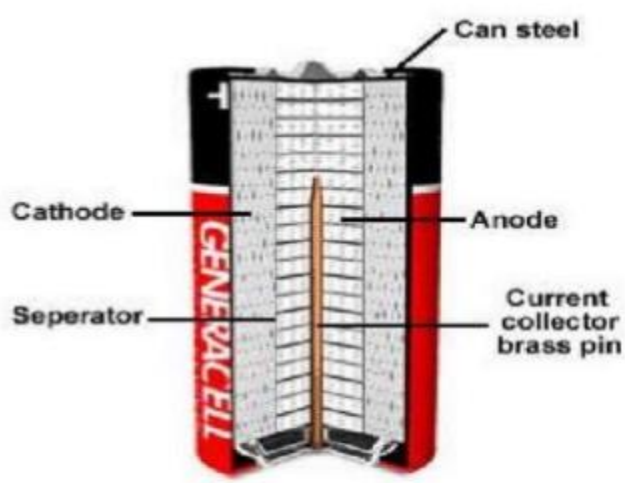


Electrodes and Electrolytes

- Cathode
  - Positive terminal
  - Chemical reduction occurs (gain electrons)
- Anode
  - Negative terminal
  - Chemical oxidation occurs (lose electrons)
- Electrolytes allow:
  - Separation of ionic transport and electrical transport
  - Ions to move between electrodes and terminals
  - Current to flow out of the battery to perform work

Battery Overview

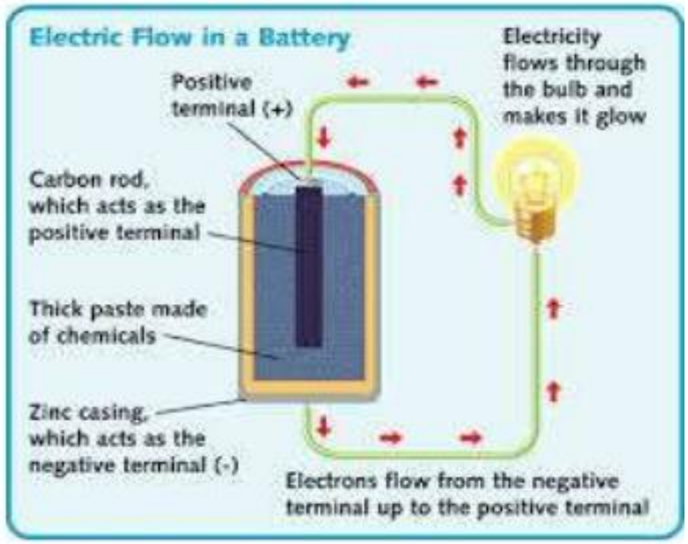
- Battery has metal or plastic case
- Inside case are cathode, anode, electrolytes
- Separator creates barrier between cathode and anode
- Current collector brass pin in middle of cell conducts electricity to outside circuit



Primary Cell

- One use (non-rechargeable/disposable)
- Chemical reaction used, can not be reversed
- Used when long periods of storage are required
- Lower discharge rate than secondary batteries
- Use:

  smoke detectors, flashlights, remote controls



Alkaline Battery

- Alkaline batteries name came from the electrolyte in an alkane
- Anode: zinc powder form
- Cathode: manganese dioxide
- Electrolyte: potassium hydroxide
- The half-reactions are:

$$Zn_{(s)} + 2OH^{-}_{(aq)} \rightarrow ZnO_{(s)} + H_2O_{(l)} + 2e^{-}\ [e^{\circ} = -1.28\ V]$$

$$2MnO_{2(s)} + H_2O_{(l)} + 2e^{-} \rightarrow Mn_2O_{3(s)} + 2OH^{-}_{(aq)}\ [e^{\circ} = 0.15\ V]$$

- Overall reaction:

$$Zn_{(s)} + 2MnO_{2(s)} \rightarrow ZnO_{(s)} + Mn_2O_{3(s)}\ [e^{\circ} = 1.43\ V]$$

Zinc-Carbon Battery

- Anode: zinc metal body (Zn)
- Cathode: manganese dioxide (MnO_2)
- Electrolyte: paste of zinc chloride and ammonium chloride dissolved in water
- The half-reactions are:

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}\ [e^{\circ} = -0.763\ V]$$

$$2NH_4^{+}(aq) + 2MnO_2(s) + 2e^{-} \rightarrow Mn_2O_3(s) + H_2O(l) + 2NH_3(aq) + 2Cl^{-}\ [e^{\circ} = 0.50\ V]$$

- Overall reaction:

$$Zn(s) + 2MnO_2(s) + 2NH_4Cl(aq) \rightarrow Mn_2O_3(s) + Zn(NH_3)_2Cl_2\ (aq) + H_2O(l)\ [e^{\circ} = 1.3\ V]a$$

Primary Cell

- **Alkaline Battery**
- Zinc powered, basic electrolyte
- Higher energy density
- Functioning with a more stable chemistry
- Shelf-life: 8 years because of zinc powder
- Long lifetime both on the shelf and better performance
- Can power all devices high and low drains
- Use:

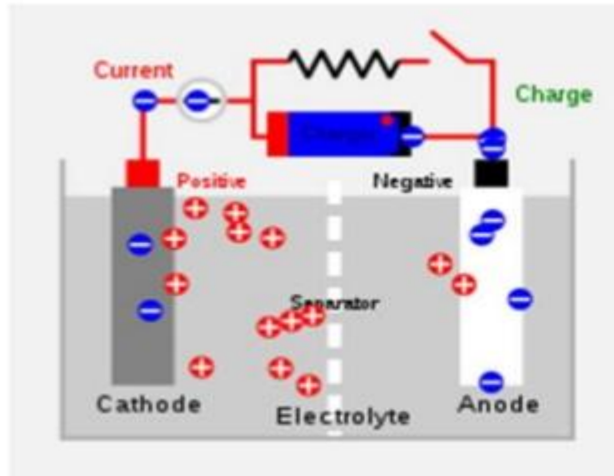
  Digital camera, game console, remotes

- **Zinc-Carbon Battery**
- Zinc body, acidic electrolyte
- Case is part of the anode
- Zinc casing slowly eaten away by the acidic electrolyte
- Cheaper then Alkaline
- Shelf-life: 1-3 years because of metal body
- Intended for low-drain devices
- Use:

  Kid toys, radios, alarm clocks

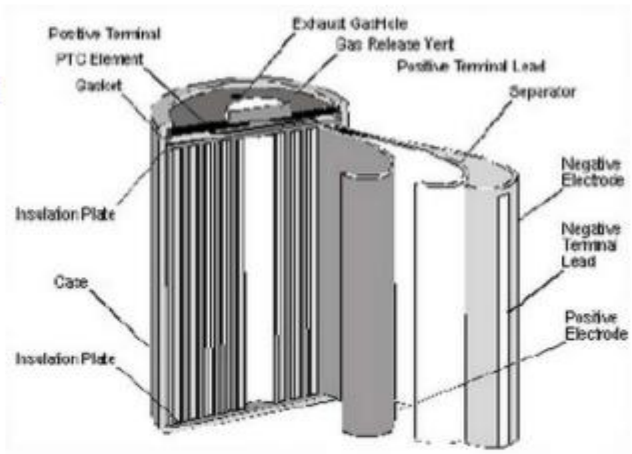
Secondary Cells

- Rechargeable batteries
- Reaction can be readily reversed
- Similar to primary cells except redox reaction can be reversed
- Recharging:
  - Electrodes undergo the opposite process than discharging
  - Cathode is oxidized and produces electrons
  - Electrons absorbed by anode



Nickel-Cadmium Battery

- Anode: Cadmium hydroxide, $Cd(OH)_2$
- Cathode: Nickel hydroxide, $Ni(OH)_2$
- Electrolyte: Potassium hydroxide, KOH



- The half-reactions are:

  $Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$

  $2NiO(OH) + Cd + 2e^- \rightarrow 2Ni(OH)_2 + 2OH^-$

- Overall reaction:
  $2NiO(OH) + Cd + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2$

Nickel-Cadmium Battery

- Maintain a steady voltage of 1.2v per cell until completely depleted
- Have ability to deliver full power output until end of cycle
- Have consistent powerful delivery throughout the entire application
- Very low internal resistance
- Lower voltage per cell

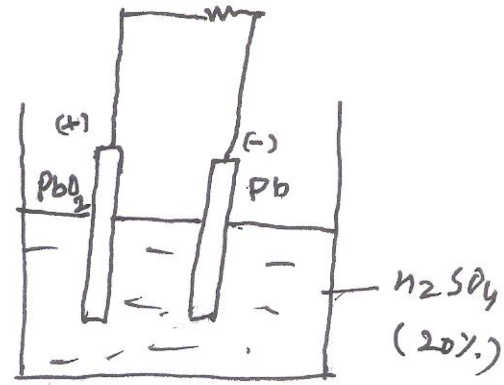
Nickel-Cadmium Battery

- Advantages:
  - This chemistry is reliable
  - Operate in a range of temperatures
  - Tolerates abuse well and performs well after long periods of storage

- Disadvantages:
  - It is three to five times more expensive than lead-acid
  - Its materials are toxic and the recycling infrastructure for larger nickel-cadmium batteries is very limited

Lead - Acid Battery

Anode — Pb
Cathode — PbO_2
Electrolyte - H_2SO_4 (20%)



The cell reactions (discharge)

Anode $Pb + SO_4^{2-} \longrightarrow PbSO_4 + 2e^-$

cathode $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \longrightarrow PbSO_4 + 2H_2O$

overall reaction $Pb + PbO_2 + 2H_2SO_4 \rightarrow PbSO_4 + 2H_2O$

The cell reactions (charging)

Anode $PbSO_4 + 2H_2O \rightarrow PbO_2 + 4H^+ + SO_4^{2-} + 2e^-$

Cathode $PbSO_4 + 2e^- \longrightarrow Pb + SO_4^{2-}$

overall $2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2H_2SO_4$

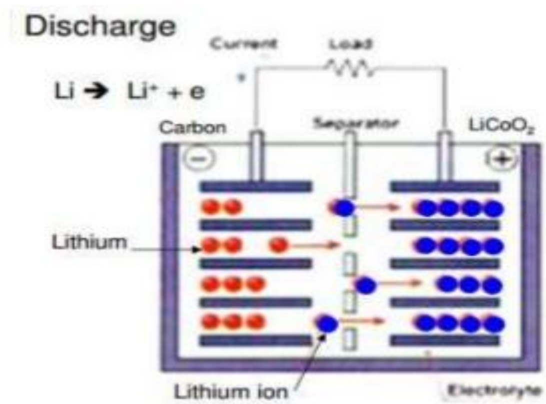
Reactions show that conc. of H_2SO_4 decreases during discharging and increases during charging.

Lead-Acid Battery

- The lead-acid cells in automobile batteries are wet cells
- Deliver short burst of high power, to start the engine
- Battery supplies power to the starter and ignition system to start the engine
- Battery acts as a voltage stabilizer in the electrical system
- Supplies the extra power necessary when the vehicle's electrical load exceeds the supply from the charging system

Lithium-Ion Battery

- Anode: Graphite
- Cathode: Lithium manganese dioxide
- Electrolyte: mixture of lithium salts



- Lithium ion battery half cell reactions

  $CoO_2 + Li^+ + e^- \leftrightarrow LiCoO_2\, E^\circ = 1V$

  $Li^+ + C_6 + e^- \leftrightarrow LiC6\; E^\circ \sim -3V$

- Overall reaction during discharge

  $CoO_2 + LiC_6 \leftrightarrow LiCoO_2 + C_6$

  $E_{oc} = E^+ - E^- = 1 - (-3.01) = 4V$

Lithium-Ion Battery

- *Advantages:*
  - It has a high specific energy (number of hours of operation for a given weight)
  - Huge success for mobile applications such as phones and notebook computers

- *Disadvantages:*
  - Cost differential
    - Not as apparent with small batteries (phones and computers)
    - Automotive batteries are larger, cost becomes more significant
  - Cell temperature is monitored to prevent temperature extremes
  - No established system for recycling large lithium-ion batteries