2

Battery Technology

2.1 INTRODUCTION

Battery is a compact device consisting of two or more galvanic cells, which convert the chemical energy into electrical energy by means of an electrochemical reaction called oxidation reduction (redox reaction). Thus, a battery acts as portable source of electrical energy.

Demand for portable power sources is ever increasing to meet diverse range of new applications such as watches, hearing aids, flashlights, radiosets, electric clocks, photoflash devices, emergency lighting, distress signalling, tape recorders, alarm systems, hand tools, toys, calculators, cordless appliances, telephone systems, electric bells, space vehicles, motor ignition and a host of other applications.

2.2 BATTERY

"Battery is a device that constitutes two or more number of galvanic cells connected in series or parallel or both which convert chemical energy into electrical energy through electrochemical reaction."

or

The arrangement of two or more cells normally coupled in series to produce higher potential is called battery.

Example: Lead – Acid Battery, Nickel – cadmium battery, etc.

2.3 BASIC COMPONENTS OF A BATTERY

A battery cell consists of four major components.

2.3.1 Anode

An anode is a negative electrode, where the oxidation reaction occurs which liberates electron into the external circuit during electrochemical reaction

$$M \longrightarrow M^{n+} + ne$$

Example: Cellulose, cellophane, etc.

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

2.4 CLASSIFICATION OF BATTERIES

Electrochemical cells or batteries are identified as primary (non-rechargeable) or secondary (rechargeable) depending on their capability of being electrically recharged. The batteries are classified as:

1. Primary batteries (non-rechargeable)
2. Secondary batteries (chargeable)
3. Reserve batteries (chargeable)

2.4.1 Primary Batteries

These are not rechargeable batteries, because the cell reactions are irreversible, i.e., when most of the reactant parts have been converted to products, no more electricity is produced and the battery becomes dead) and are to be discarded after the use. Such batteries are called primary batteries.

Example: Zn–MnO_2, Li–MnO_2, etc.

2.4.2 Secondary Batteries

These are rechargeable batteries, because the cell reaction are reversible. They are also called storage batteries, as they are the storage devices for electrical energy. The discharged cell can be recharged by passing current through it in the direction opposite to that of discharge current.

Example: Lead – Acid Battery, Mi–Cd battery, etc.

2.4.3 Reserve Batteries

Reserve batteries have long shell life and extreme storage. In this type of battery, one of the components is stored separately and is incorporated into the battery when required; usually the electrolyte is the component that is isolated.

Example: Magnesium batteries activated by water (Mg –AgCl and Mg –CuCl)

It is used to deliver high power for relatively short periods of time in applications such as missiles, torpedoes and other weapon systems.

2.5 CHARACTERISTICS OF BATTERIES

A single battery may not exhibit all good characteristics, but a battery can be designed and constructed with specific characteristics for a particular application.

2.5.1 Capacity

The capacity of a battery is expressed as the total amount of electricity or charge that may be obtained from the battery. It is given in ampere hours (Ah). It depends on the size of the battery. It is determined by the Faraday's relation.

$$C = WnF/M$$

where, $W \rightarrow$ Weight of the active material
$M \rightarrow$ Molecular weight of the material
$n \rightarrow$ No. of $_{-1}e^{\circ}$ transferred per mole of reaction
$F \rightarrow$ Faraday's constant
$C \rightarrow$ Capacity in Ah

Higher the capacity, higher is the efficiency of the battery.

It is measured by plotting time against the voltage at a fixed current discharge. More is the length of the flat portion of the curve, better is the capacity of the battery.

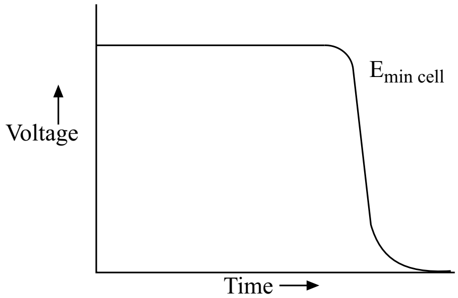

Fig. 2.2 *Voltage against time for fixed current discharge*

2.5.2 Current

The rate of discharge of battery is called current of battery. Higher the potential difference in active materials faster the reaction and higher will be the rate of discharge of battery.

It is determined by the Ohm's law

$$I = V/R$$

where, $I \rightarrow$ Current
$V \rightarrow$ A difference in potential between anode and cathode
$R \rightarrow$ Resistance offered by the cell.

At higher resistance more potential difference is required to force the current through the cell.

2.5.3 Power Density

It measures how quickly the battery can deliver energy. It is measured in W/kg

$$\text{Power density} = \frac{I_E}{W}$$

where, $I \rightarrow$ Current drawn from the battery
$E \rightarrow$ Voltage
$W \rightarrow$ Weight of the battery

According to Nernst equation

$$E_{\text{cell}} = E_{\text{cell}} \frac{2.303\,RT}{nF} \log \frac{[M_1^{n+}]}{[M_2^{2+}]}$$

$$E_{\text{cell}} = E_{\text{cell}} + \frac{0.0591}{n} \frac{[M_2^{n+}]}{[M_1^{n+}]}$$

More the number of the cells, higher is emf and more efficient is the battery, similarly, higher the potential difference between electrodes of each cell, higher is the emf of the cell and more efficient is the battery.

2.5.9 Electricity Storage Density

It is a measure of the charge per unit mass stored in the battery.

The mass of the battery includes masses of the electrolyte, current collectors, terminals and other subsidiary elements. Lighter subsidiary elements lead to high storage density.

For example: 7g of lithium anode gives 96500 C whereas, for the same charge, 65 g of zinc is required.

2.6 WORKING OF A BATTERY

It involves discharging (delivering power) and recharging.

2.6.1 Discharging

A battery is packed with active materials at anode and cathode. During discharge, the anode undergoes oxidation to form cations and release electrons.

At anode $M_1 \rightarrow M_1^{n+} + ne$

Hence, cationic concentration increases in the anodic compartment. The released $_{+}e^{0}$ flows from anode to cathode through external circuit and thus constitutes the flow of current.

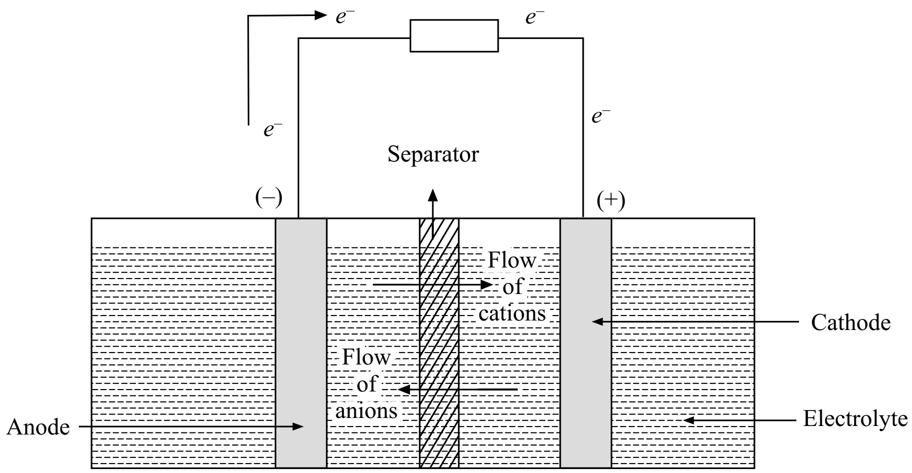

Fig. 2.3 *Discharging of a battery*

At cathode, electrons are accepted for the reduction of the metal ions (cations) to metal atoms (which get deposited on cathode) and hence anionic concentration becomes more in the cathodic compartment.

At cathode: $M_1^{n+} + ne^- \rightarrow M_2$

Thus, during discharge concentration of active species at anode gradually decreases hence the emf of the battery decreases.

2.6.2 Charging

In this process, the current flow is reversed with the aid of a dc power supply. The negative terminal of the power supply is connected to the anode of the battery and positive terminal to the cathode of the battery. Under this condition metal ions are reduced to metal atoms (which get deposited on anode) at the anode and anionic concentration increases in anodic compartment.

At anode: $M_1^{n+} + ne^- \rightarrow M_1$

At cathode, oxidation occurs by releasing electrons and hence, cationic concentration increases in cathodic compartment.

At anode: $M^2 \rightarrow M_2^{n+} + ne^-$

Thus, during recharge, the positive electrode acts as anode and the negative electrode acts as cathode. It means electrode reactions are reversed. Hence, original emf of the battery will be restored.

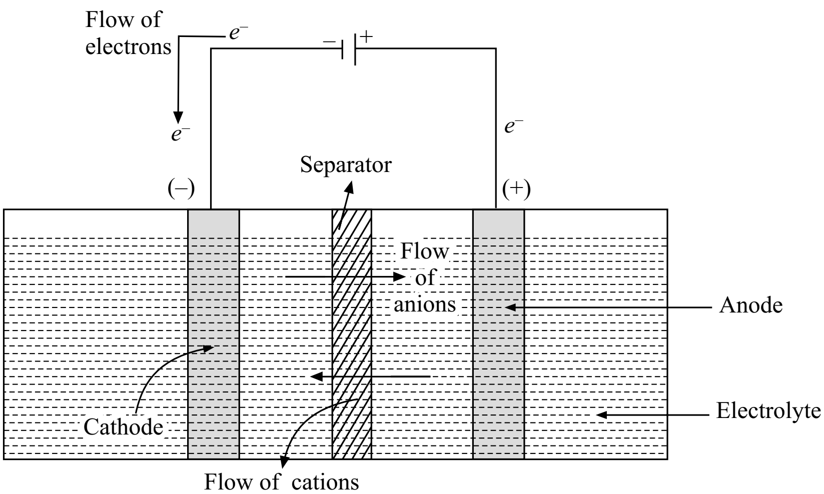

Fig. 2.4 *Charging of a battery*

2.7 MODERN BATTERIES

Many commercial batteries are not able to meet the performance requirements of many applications. Thus, a continual need exists for both conventional battery technology with improved performance and advance battery technologies with high energy level, long life, low cost, little or no maintenance and safety.

Advantages

1. Ecofriendly
2. Light and have high energy density
3. Unlimited capacity
4. Suffer from long shelf life, still they are known for low energy cast.

Disadvantages

1. Limited power output
2. Short activated life

Applications

1. Portable battery chargers
2. Several medical devices
3. Voice transmitters
4. Electronic pagers
5. Remote communications

2.7.2 Nickel-metal Hydride Batteries

Nickel – metal hydride batteries are alkaline rechargeable batteries and were commercialized in 1990. It has better cycle life and high power density which makes it highly useful in auto mobiles.

Construction:

The anode: Porous nickel grid pasted with hydrides of metals like VH_2, ZrH_2 and TiH_2 with a hydrogen storage metal alloy such as $TiNi_2$ or $LaNi_5$.

The anode material has:

1. A good hydrogen storage capacity capable of adsorbing and desorbing hydrogen as the battery is discharged and charged.
2. High resistance to chemical oxidation and corrosion.
3. High electrochemical reactivity.

The cathode: Porous nickel grid pasted with $Mi(OH)_2$

The electrolyte: Aqueous KOH solution used as an electrolyte.

Electrode materials are separated by a synthetic non-woven material which serves as separator as well as medium for absorbing the electrolyte.

The cell is represented as:

$$MH_2\ M \mid KOH \mid NiO\ (OH)\ Ni\ (OH)_2$$

Reaction:

At the anode:

$$MH_2 + 2OH^- \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} 2H_2O + M + 2e^-$$

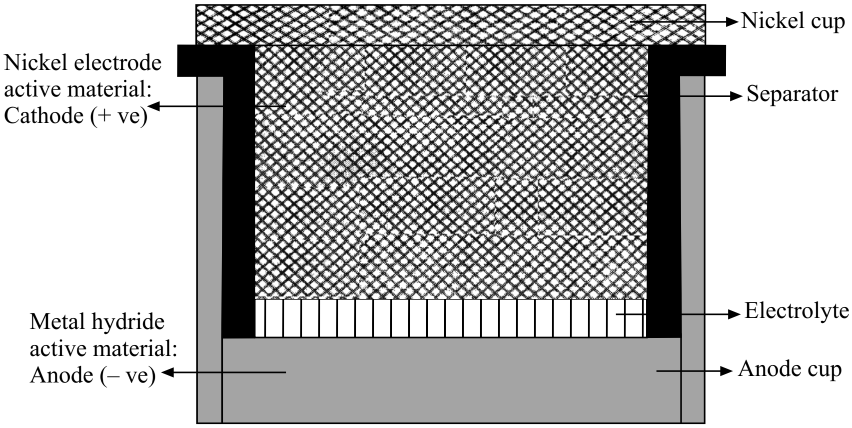

Fig. 2.6 *Nickel-Metal hydride cell*

At the cathode:

$$2\,NiO(OH) + 2H_2O + 2e^- \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} 2\,Ni(OH)_2 + 2OH$$

The overall cell reaction is:

$$MH_2 + 2OH^- \longrightarrow M + 2H_2O + 2e^-$$
$$(NiO\,(OH) + H_2O + e- \longrightarrow Mi\,(OH)_2 + OH^-) \times 2$$
$$MH_2 + 2NiO\,(OH) \longrightarrow M + 2Ni\,(OH)_2$$

From the above reaction, we can say that in Mi-MH battery hydrogen moves from +ve to –ve electrode during charge and in reverse order during the discharge with the electrolyte taking no part in the reaction.

The emf of the battery is 1.25 – 1.35 V

Advantages

1. High capacity
2. Sealed construction
3. Long cycle life
4. Rapid recharge capability
5. Cadmium free-minimal environmental problems, long shelf life

Disadvantage

Performance is not as good as of nickel – cadmium batteries.

Applications

1. In electric vehicles, computers, cellular phone, spacecraft.
2. Portable electronic equipment.

3. **The electrolyte:** It contains a mixture of lithium salt (LiCl, LiBr, $LiClO_4$, $LiAlCl_4$) dissolved in a mixed organic solvent of propylene carbonate and 1,2-dimethoxy ethane.
   Water is not used as a solvent since lithium is highly reactive in water, whereas rate of corrosion of Li is slow in organic solvents.
   Anode and cathode are separated by a non-woven polypropylene separator.

Cell Representation

$Li \mid LI^+ \mid$ Lithium salt inorganic solvent $\mid Mn^{(IV)} O_2 \mid Mn^{(III)} O_2$

Reactions:

At the anode: $Li \longrightarrow Li^+ + e^-$

At the cathode: $Mn^{(IV)} O_2 + Li^+ + e^- \longrightarrow Li^{(+)} Mn^{(III)} O_2$

Overall cell reaction: $Li + Mn^{(IV)}O_2 \longrightarrow Li^+ Mn^{III} O_2$

It is observed from the above reaction, Mn is reduced from the tetravalent state (in MnO_2) to the trivalent state (in $Mn^{III} O_2 Li^+$) by Lithium. $Mn^{(III)} O_2 Li^+$ indicates that Li^+ ion enters the MnO_2 crystal lattice.

The voltage of the cell is 3.5 V.

Characteristics

1. Relatively low cost
2. High volumetric and gravimetric energy density
3. Performance at high discharge rate
4. Light in weight and compact
5. Wide operating temperature range (–20 to 55°C)

Applications

1. Automatic cameras
2. Portable televisions and calculators
3. Long-term memory back-up
4. Many consumer electronic devices
5. Lighting equipment
6. Safety and security devices

2.8.2 Li–ion Battery

In this type of battery, lithium ions are used instead of lithium ion through electrolyte takes place from one electrode to another electrode.

In general, the battery consists of soluble lithium anode as ion into carbon, and the cathode material is made up of lithium liberating compounds.

Example: Lithium cobalt oxide ($LiCoO_2$) battery.

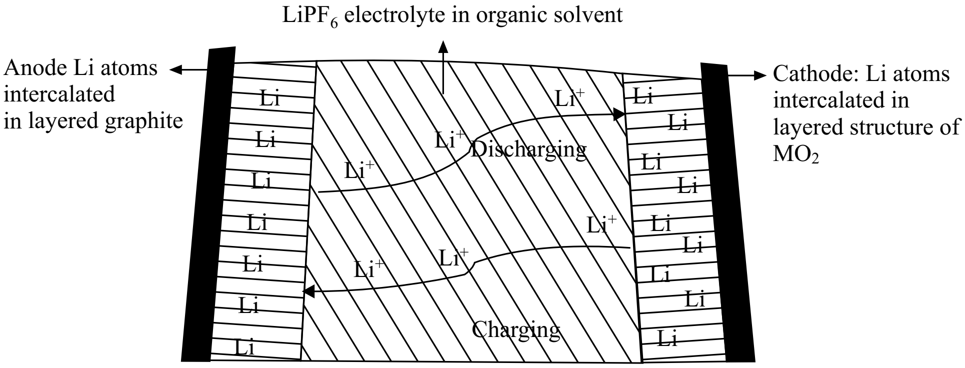

Fig. 2.8 *Lithium ion rechargeable battery*

Construction

1. **The anode:** Anode is made up of carbon electrode with thin copper foil as current collector.
2. **The cathode:** It is made up of lithium metal oxide compound (Li–MO_2) where M is commonly Co or Mn.
3. **Electrolyte:** A lithium salt such as $LiPF_6$ dissolved in binary organic solvent mixture such as ethylene carbonate – dimethyl carbonate. (Fig. 2.8).

Cell Representation

$$Li \mid Li^+, C \mid LiPF_6 \text{ in ethylene carbonate} \mid Li\text{–}MO_2$$

Working

During discharging, lithium atoms are oxidized, liberating electrons and lithium ions which migrate through electrolyte to cathode.

$$Li - C_6 \longrightarrow Li^+ + 6C + e^-$$

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

$$Li^+ + e^- + MO_2 \longrightarrow Li\text{–}MO_2$$

During charging, lithium atoms of metal oxide are oxidized, liberating electrons and lithium ions. Electrons flow through the external circuit and lithium ions flow through the electrolyte towards graphite carbon electrode

$$Li - MO_2 \longrightarrow Li^+ + e^- + MO_2$$

At graphite electrode, lithium ions are reduced to lithium atoms and are inserted into the layered structure of graphite.

$$Li^+ + 6C + e^- \longrightarrow Li - C_6$$

The emf of the battery is 4.0 V.

Advantages

- They have high energy density than other rechargeable batteries.
- They are less weight.
- They produce high voltage out about 4 V as compared with other batteries.
- They have improved safety, i.e., more resistance to overcharge.

The $_{+}e^{\circ}$ liberated from the oxidation process at the anode can perform useful work when they pass through the external circuit to the cathode.

2.9.2 Principle

The basic principle of the fuel cell is same as that of electrochemical cell. The only difference is that the fuel and oxidant are stored outside the cell. Fuel and oxidant are supplied continuously and separately to the electrodes at which they undergo redox reactions.

Fuel cells are capable of supplying current as long as reactants are restore.

$$\text{Fuel + oxidant} \rightarrow \text{Oxidation products + Electricity.}$$

2.9.3 Advantages

1. High energy conversion
2. Ecofriendly (i.e., it converts a fuel to electrical energy with minimum emission of pollutants.
3. No need of charging
4. Space required for fuel cell is less
5. Maintenance is less
6. High energy density
7. No moving parts and there is no wear and tear of cell parts
8. Silent operation
9. Absence of harmful waste products
10. It generates electricity as long as fuel is supplied.

2.9.4 Disadvantages

1. The power generated is moderate
2. Cost of power is high as a result of the cost of the electrodes
3. Fuels in the form of gases and oxygen need to be stored in tanks under high pressure.

2.10 COMPARISON BETWEEN FUEL CELL AND BATTERIES

Fuel Cell	Batteries
1. Reactants (fuel and oxidant) are not part of the cell they are supplied from outside.	1. All reactants are integral parts of it.
2. Do not store chemical energy.	2. Store chemical energy.
3. The electrodes are charged with catalyst.	3. The electrodes are not helped with catalyst.
4. The electrodes in some cases are not consumed during production of energy.	4. The electrodes are consumed during production of energy.
5. Products are continuously removed from a fuel cell.	5. Products are not removed.
6. Produce current on their own.	6. Require recharging from external source of electric current.

2.11 CLASSIFICATION OF FUEL CELL

Fuel cells are classified on the basis of temperature of operation.

1. Low temperature fuel cells (less than 100 °C): which use water based electrolyte.
2. Medium temperature fuel cell (100–250 °C): which use molten salt as electrolyte.
3. High temperature fuel cell (less than 500 °C): which use ceramic electrolyte.

2.12 TYPES OF FUEL CELL

The fuel cells can be classified into different types based on the fuel and electrolytes used.

1. Alkaline fuel cell – (AFC)

- Low temperature fuel cells (80 °C) using
- Porous carbon charged with Mi/Pd acts as anode
- Porous carbon charge with Ag-catalyst acts as cathode
- Hydrogen gas is fuel at anode
- Oxygen gas is fuel at cathode
- Aqueous KOH solution is used as electrolyte

2. Phosphoric acid fuel cell: (PAFC)

- Porous C + Sic + Teflon charge with Pt-catalyst + acts as anode
- Porous C + Sic + Teflon charge with Ag-catalyst acts cathode
- Pure H_2 gas is anodic fuel
- Pure O_2 gas is cathodic fuel
- Concentrated phosphoric acid is used as electrolyte.

3. Molten carbonate fuel cell: (MCFC)

- Anode is porous Ni/Ni – Cr alloy
- Cathode is porous NiO
- H_2 gas or CO gas is fuel at anode
- O_2 gas is fuel at cathode operates between 600-650 °C
- Fused carbonates (eutectic mixture of 32% $Li_2 CO_3$ + 48% $NiAlCO_3$ + K_2CO_3) in porous inorganic material is used as electrolytic.

4. Polymer electrolyte fuel cell: (PEFC)

- Two different porous gas diffusion carbon electrodes charged with Pt acts as both anode and cathode.
- H_2 gas is used as anode fuel.
- O_2 gas is used as cathode fuel stable at 100 °C.
- Nafion membrane with 50% water as electrolyte is used as electrolyte.

  (Nafion, i.e., per fluorinated cation exchange polymer membrane)

Note:
a. KOH is not used as electrolyte as it reacts with CO_2 and gets converted into K_2CO_3. Thus, conductivity of the electrolyte decrease as well as the efficiency.
b. The advantage of acid electrolyte is that the CO_2, a product of the reaction can be easily removed.

5. A membrane is provided which prevent the diffusion of methanol into the cathode. In the absence of the membrane, methanol crosses over to the cathode compartment and undergoes oxidation there itself.

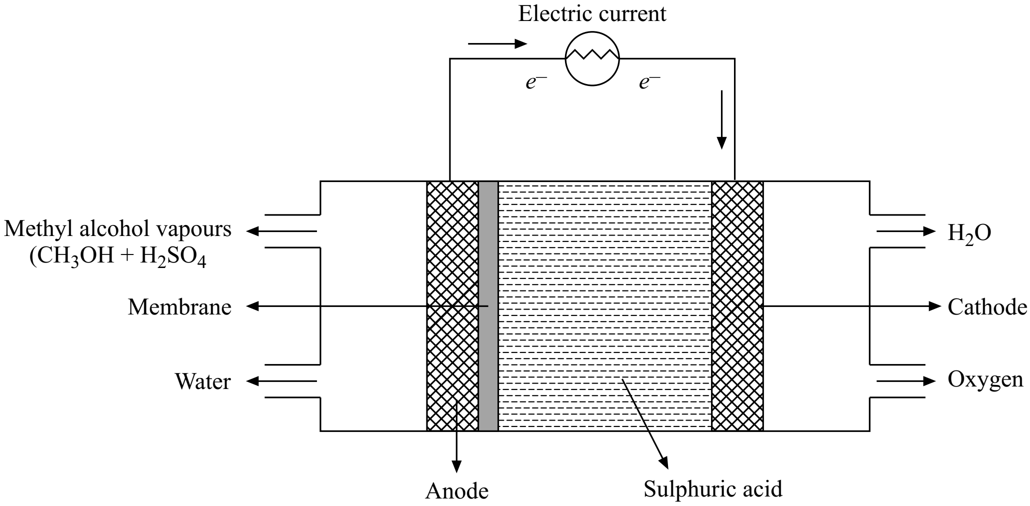

Fig. 2.9

2.14.2 Working

The electrode reactions are as follows:

Anode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathode: $3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

Overall reaction: $CH_3OH + 3/2\ O_2 \rightarrow CO_2 + 2H_2O$

The emf of the cell is 1.2 V.

Advantages

- Methanol has low carbon content OH group is easily oxidisable
- Methanol is highly soluble in water.

Applications

Used in military applications such as soldier carried equipment, power for test and training equipment, battery chargers, etc.

Objective Type Questions

1. A rechargeable cell is
(a) Leclanche cell (b) Nickel- cadmium cell
(c) Zn-MnO_2 cell (d) Storage cell

2. Which cell use to converted electrical energy into chemical energy?
(a) Electrolytic cell (b) Daniel cell
(c) Galvanic cell (d) Electrochemical cell

3. In which battery a key component is separated from the rest of battery prior to activation?
(a) Secondary battery (b) Primary battery
(c) Reserve battery (d) None of these **(VTU, Jan/Feb 09)**

4. Which of the following electrolyte is used in hydrogen oxygen fuel cell.
(a) CH_3COOH (b) KOH°
(c) NH_4OH (d) None of these **(VTU, Jan 09)**

5. The reaction that takes place at the anode of a battery is
(a) Reduction (b) Neutralisation
(c) Oxidation (d) Addition **(VTU, Jan 09)**

6. Which of the following is not a rechargeable battery?
(a) Ni-Cd (b) Zn-air
(c) Zn-MnO_2 (d) Li-MnO_2 **(VTU, Jan 09)**

7. Li-MnO_2 has higher emf than Zn-MnO_2 battery because
(a) Li is more electro +ve than Zn (b) Li undergoes oxidation readily
(c) SRP of Li is less than Zn (d) All of these. **(VTU, May/June 10)**

8. In H_2–O_2 fuel cell the electrolyte KOH is kept in warm condition to
(a) Maintain the electrolyte concentration
(b) Increase the emf (c) Increase the efficiency
(d) Increase the conductivity **(VTU, May/June 10)**

9. The fuel cell involving solid electrolyte is
(a) Solid oxide (b) Molten carbonate
(c) Polymer electrolyte (d) None of these **(VTU, May/June 10)**

10. Fuel cells are superior to the conventional batteries because
(a) they are light in weight (b) they are ecofriendly
(c) they produce direct current at low cost
(d) they are easily fabricated **(VTU June/July 09)**

11. The electrolyte used in Zn-Air battery is
(a) aqueous sulphuric acid (b) aqueous potassium hydroxide
(c) concentrated potassium chloride (d) none of these **(VTU, June/July 09)**

12. Which of the following is a reserve battery
(a) Zn- Air (b) Mi-MH
(c) Zn-Ag_2O (d) Li-MnO_2 **(VTU, June/July 09)**

13. In which of the following the net cell reaction is irreversible?
(a) Pb-H_2SO_4 (b) Mi-MH
(c) Zn-MnO_2 (d) Ni-Cd

14. Which property is true to derive the maximum voltage from a battery.
(a) Internal resistance must be low
(b) The over potential at the electrodes must be low
(c) The difference in the electrode potential must be high
(d) All of the above

15. When comparing fuel cell with the conventional cell, which of the following is incorrect?
(a) It stores the energy (b) It is ecofriendly
(c) It is a device (d) It performs silent operation

16. What is the cycle life of a rechargeable battery?
(a) No. of charging of a battery
(b) No. of times a battery is used till satisfactory performance
(c) No. of discharge of a battery
(d) No. of discharging and charging cycles of a battery till satisfactory performance

17. Which is the example of primary cell?
(a) Ni-MH (b) Ni-Cd (c) Zn-MnO_2 (d) Lead acid

18. Why battery is known as rechargeable battery?
(a) Battery cannot store energy
(b) Does not contribute for electrical conductivity
(b) Overall redox reactions are thermodynamically reversible
(d) Battery cannot be charged

19. In Li-MnO_2 cell, lithium ions
(a) not a intercalation lithium ions (b) do not contribute for electrical conductivity
(c) diffuse through layered structure of MnO_2
(d) none of the above.

20. Which is the cathode of Zn-air cell?
(a) Zn/air (b) air/C° (c) Air/KOH (d) Graphite

ANSWERS

1. (b)	**2.** (c)	**3.** (c)	**4.** (b)	**5.** (c)	**6.** (c)
7. (d)	**8.** (c)	**9.** (a)	**10.** (b)	**11.** (a)	**12.** (b)
13. (c)	**14.** (c)	**15.** (a)	**16.** (d)	**17.** (c)	**18.** (c)
19. (c)	**20.** (b)				

19. What are rechargeable and reserve batteries? **(VTU, July, 2012)**

20. Explain the following battery characteristics:
(a) Voltage (b) Cycle life (c) Energy efficiency **(July, 2011)**

21. Give the classification of fuel cells on the basis of temperature and electrolyte.

22. Write short notes on the following:

(a) Nickel-cadmium battery. **(Bombay, B.Sc (H) 05)**

(b) Zinc-air battery. **(Punjab, B.Sc (H) 03)**

(c) Nickel-metal hydride battery. **(Karnataka, BSC (H) 04)**

(d) Lithium battery. **(Poona, B.Sc (H) 05)**

(e) Rechargeable lithium-ion battery. **(Calicut, B.Sc. (H) 03)**

23. Give the characteristics of fuel cells. **(Bombay, BSc. (H) 02)**

24. Give the characteristics of zinc-air battery. **(Bombay, BSc. (H) 04)**

25. What are fuel cells? Indicate the advantages of fuel cells. Explain methanol – oxygen fuel cells with the reactions involved. **(VTU, Aug 04)**