Primary and Secondary cells

Primary cells and secondary cells are two types of electrochemical cells that convert chemical energy into electrical energy. The main difference between them lies in their ability to be recharged.

1. **Primary Cells:**
   - **Definition:** Primary cells are non-rechargeable cells, meaning once they are depleted, they cannot be recharged and reused.
   - **Chemistry:** They typically use irreversible chemical reactions to generate electrical energy. Common examples include zinc-carbon batteries and alkaline batteries.
   - **Use:** Primary cells are often used in situations where recharging is impractical or not possible. They are commonly found in devices like remote controls, flashlights, and some electronic gadgets.
2. **Secondary Cells:**
   - **Definition:** Secondary cells are rechargeable cells, meaning they can be charged and discharged multiple times.
   - **Chemistry:** They use reversible chemical reactions, allowing the cell to be recharged by applying an external electrical current. Examples include lead-acid batteries, nickel-cadmium (NiCd) batteries, nickel-metal hydride (NiMH) batteries, and lithium-ion batteries.
   - **Use:** Secondary cells are used in applications where it is more economical and convenient to recharge the cell rather than replacing it after a single use. They are common in devices such as laptops, mobile phones, electric vehicles, and other portable electronic devices.

Zinc-Air cell

Zinc-Air cell is a type of electrochemical cell that generates electrical power through the reaction of zinc with oxygen from the air. It is a type of metal-air battery, where one of the electrodes (anode) is made of zinc, and the cathode is exposed to oxygen from the air.

1. **Zinc Anode:** The anode is typically made of zinc metal. During the cell's discharge (when it is providing electrical power), zinc undergoes oxidation, releasing electrons.

2. **Air Cathode:** The cathode is exposed to oxygen from the air. It is usually a porous material that allows oxygen to diffuse into the cell. At the cathode, oxygen undergoes reduction by accepting electrons from the external circuit.

3. **Electrolyte:** A suitable electrolyte, often a potassium hydroxide (KOH) solution, is used to facilitate the movement of ions between the anode and cathode. The electrolyte provides a medium for the transfer of ions during the electrochemical reactions.

4. **Separator:** A separator is employed to prevent direct contact between the zinc anode and the air cathode, avoiding short circuits within the cell.

Working of Zinc-Air Cell:

The zinc-air cell operates through a series of electrochemical reactions that occur during both discharge and recharge.

Cell Discharge:

1. At the zinc anode, zinc undergoes oxidation, producing zinc ions (Zn^{2+}) and releasing electrons: $Zn \rightarrow Zn^{2+} + 2e-$

2. Electrons flow through the external circuit, creating an electric current that can be used to power electronic devices.

3. At the air cathode, oxygen from the air combines with water and electrons to form hydroxide ions: $1/2O_2 + H_2O + 2e- \rightarrow 2OH^-$

   Zinc ions move through the electrolyte to the air cathode, where they combine with hydroxide ions to form zincate ions:

   $Zn^{2+} + 2OH^- \rightarrow Zn(OH)_2$

Lithium-ion (Li-ion) battery

A Lithium-ion (Li-ion) battery is a type of rechargeable battery that has become widely popular for various applications due to its high energy density, lightweight design, and relatively long cycle life. Li-ion batteries are commonly used in portable electronic devices, electric vehicles, renewable energy systems.

A lithium-ion (Li-ion) battery consists of several key components:

1. **Cathode:** The cathode is typically made of a lithium metal oxide, such as lithium cobalt oxide ($LiCoO_2$), lithium manganese oxide ($LiMn_2O_4$), or lithium iron phosphate ($LiFePO_4$). The cathode is a source of lithium ions during the battery's operation.

2. **Anode:** The anode is usually made of graphite, and it serves as a host for lithium ions during charging and as a source of electrons during discharging.
3. **Separator:** The separator is a permeable membrane that keeps the cathode and anode apart to prevent a short circuit while allowing the flow of lithium ions between them.
4. **Electrolyte:** The electrolyte is a lithium salt dissolved in a solvent. It facilitates the movement of lithium ions between the cathode and anode during the electrochemical reactions.

The reactions occurring in a lithium-ion battery involve the movement of lithium ions between the anode and cathode, with an electrolyte facilitating the transport of ions.

Discharge (or usage) reaction at the anode:

$LiC_6 \rightarrow Li + e^- + C_6$

Discharge (or usage) reaction at the cathode:

$LiCoO_2 + Li^+ + e- \rightarrow Li_2CoO_2$

Overall discharge reaction:

$LiC_6 + LiCoO_2 \rightarrow Li_2CoO_2 + C_6$

Charge reactions

During the charging process, lithium ions are driven back from the cathode to the anode. The anode reaction is essentially the reverse of the discharge reaction:

Anode (during charging): $Li^+ + e^- + C_6 \rightarrow LiC_6$
Cathode (during charging): $Li_2CoO_2 \rightarrow LiCoO_2 + Li^+ + e-$

Overall charging reaction:

$Li_2CoO_2 + C_6 \rightarrow LiC_6 + LiCoO_2$

Hydrogen-Oxygen Fuel Cell

A hydrogen-oxygen fuel cell, also known as a proton exchange membrane (PEM) fuel cell, consists of several components:

1. **Anode:** The anode is the negative electrode where hydrogen gas is supplied. Typically, a platinum catalyst is used to facilitate the electrochemical reaction.

2. **Cathode:** The cathode is the positive electrode where oxygen (usually from the air) is supplied. A platinum catalyst is also employed at the cathode.

3. **Proton Exchange Membrane (PEM):** The PEM is a solid polymer electrolyte that separates the anode and cathode. It allows the passage of protons (hydrogen ions) while blocking the passage of electrons.

4. **Electrolyte:** In the case of PEM fuel cells, the electrolyte is the PEM itself. It plays a crucial role in facilitating the movement of protons from the anode to the cathode.

5. **Bipolar Plates:** These plates are used to connect individual cells in a fuel cell stack, providing electrical conductivity and facilitating the flow of reactants and products.

Working of Hydrogen-Oxygen Fuel Cell:

The overall operation of a hydrogen-oxygen fuel cell involves the electrochemical reaction between hydrogen and oxygen to produce electricity.

1. **Anode Reaction (Oxidation):** $H_2 \rightarrow 2H^+ + 2e-$

At the anode, hydrogen gas (H_2) is split into protons (H^+) and electrons (e^-). The protons move through the PEM to the cathode.

2. **Cathode Reaction (Reduction):** $1/2O_2 + 2H^+ + 2\ e- \rightarrow H_2O$

At the cathode, oxygen from the air combines with protons and electrons to form water (H_2O).

3. **Overall Cell Reaction:** $H_2 + 1/2O_2 \rightarrow H_2O$

The overall reaction demonstrates the conversion of hydrogen and oxygen into water, releasing electrical energy in the process.

4. **Electron Flow:** Electrons released at the anode cannot pass through the PEM. Instead, they travel through an external circuit, creating an electric current that can power electrical devices or systems.

5. **Proton Movement:** Protons generated at the anode move through the PEM to the cathode, where they combine with oxygen and electrons to form water.

6. **Water Formation:** At the cathode, water is the only byproduct of the electrochemical reactions.

Advantages:

- The only byproduct is water, making fuel cells environmentally friendly.
- High efficiency and energy density.
- Can provide continuous power as long as hydrogen and oxygen are supplied.

Challenges:

- Hydrogen production, storage, and distribution pose challenges.
- Cost of materials, especially platinum catalysts.
- Durability and lifetime concerns.

Hydrogen-oxygen fuel cells are used in various applications, including vehicles, backup power systems, and portable electronics, where clean and efficient power generation is desirable. Ongoing research aims to address challenges and improve the commercial viability of fuel cell technology.