TASK – 5

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BATTERIES

- **HISTORY : -**

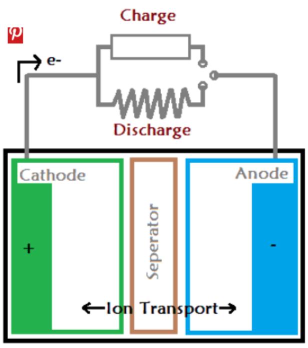
1. ***Voltaic Cell*** - A voltaic cell uses chemical reaction to produce electrical energy. One anode and cathode are made opposite to each other. At anode, oxidation occurs and reduction occurs at cathode. A salt bridge is created in between to complete the circuit. The parts where oxidation and reduction occur are called half cells. An external circuit is used to conduct the flow of electrons.

2. ***Daniel Cell*** - In this cell type, a container divided into two compartments. The gap was made by a membrane permeable to ions. In one of the components, Zinc electrolyte was dipped in a Zinc sulfate solution. In the other compartment, a copper electrode in a copper sulfate solution was dipped. The cell was capable of delivering current until it runs out of Zinc or Copper sulfate.

- **General Chemistry of Battery : -**

A battery have three layers the cathode, anode and a separator. The negative layer of the battery is called as anode and the positive layer is called as cathode. When a load is attached with the battery the current starts flowing through the anode to cathode. Similarly, when we connect the battery charger the current starts flowing into the opposite direction i.e. cathode to anode.

Every battery work on a chemical reaction called oxidation-reduction reaction. The reaction take place in between the cathode and the anode via the separator (electrolyte).



- **Different Types of Batteries**

    1. Primary Cell
    2. Secondary Cell
    3. Reserve Cell
    4. Fuel Cell

1. ***Primary Cell (Non-rechargeable Batteries)- N***on-rechargeable batteries also known as primary batteries or primary cell. Primary batteries are those which cannot be used again once their stored energy is being used fully. These batteries cannot restore energy by any external source. This is the reason primary cells are also called disposable batteries.

A major factor reducing the lifetime of primary batteries is that they become polarized during use. To extend the battery life by reducing the effect of polarization, chemical depolarization is used i.e. oxidizing the hydrogen to water by adding an oxidizing agent to the cell. Like as, in zinc-carbon cell and Leclanche cell Manganese dioxide is used, and in Bunsen cell and Grove cell nitric acid is used.

- ***Applications of Primary Cells:***

2. They can be used in clock and toys
3. It can be used in small household devices
4. It can be used in personal computers
5. It can be used in portable emergency lights and inverters

- ***TYPES : -***
    1. Zinc-Carbon Battery (aka. 'Heavy Duty')
    2. Alkaline
    3. Lithium Cells
    4. Silver Oxide Cells
    5. Zinc Air Cells

- ***Zinc-Carbon Battery -*** Zinc-carbon batteries are first commercial dry batteries which provide very low power and are also known as dry cell. A carbon rod is placed in the battery, which collects the current from the manganese dioxide electrode. It can give a 1.5Volts of DC supply. These types of batteries are used in Flashlight, radios, remote controls, and wall clocks.

- ***Alkaline -*** Alkaline is also a dry cell battery, it consists of zinc anode and manganese dioxide cathode. The alkaline battery is packed with steel can and the outermost inner region is filled with manganese dioxide. Zinc and the potassium hydroxide electrolyte is filled in the center most region of the battery. Alkaline batteries have higher density then the other batteries. Generally, it is used in Audio players, radios and the torch lights.

- ***Lithium Cells -*** Lithium cell batteries are comes in coin or button type design form. It provider higher voltage (3V) value than the zinc, alkaline and manganese batteries. Lithium cells are smaller in size and lighter in weight. The internal resistance of lithium cells are high and they are not rechargeable. The most popular coin cell used in number of electronics application is CR2032 which provides 3V output. Lithium cells have longer life span (around 10 years).

- ***Silver Oxide Cells: -*** Silver oxide batteries are low power batteries with high capacity. They are similar in appearance to mercury cells and provides a higher emf of 1.5 volt. The cathode of the battery is made up of silver oxide. The electrolyte present inside the battery is made of potassium or sodium hydroxide. As silver is expensive, this battery has very limited applications.

The excellent features of silver oxide cells are:

The unique sealing of the battery structure makes the battery highly leak-proof.
Constant voltage output given by the battery makes it useful to get stable discharge
The use of antioxidants contributes to the high energy density of the battery.

Applications of silver oxide cells:

- IOT based devices
- Electric watches
- Precision instruments
- Medical devices

- ***Zinc Air Cells -*** A zinc air battery reaches full operating voltages within 5 mins right after un-sealing. These are primary batteries with rechargeable designs. The oxygen content in the air acts as the active mass of the battery. The cathode is a porous body made up of carbon with air access. The output voltage capability of the cell is 1.65 volts. While discharge, a mass of zinc particle forms a porous anode saturated with an electrolyte. The oxygen present in the air reacts with the hydroxyl ion and form zincate. This Zincate forms zinc oxide and water returns to the electrolyte.

1. Secondary Cell (Rechargeable Batteries)

Rechargeable batteries are also known as secondary cell. It can be use again and again by plugging them into charge and get multiple uses before the battery needs to be replaced. The initial cost of rechargeable batteries is commonly more than disposable batteries, but the total cost of ownership and environmental impact of these batteries are lower because they can be recharged inexpensively many times before they need to replace it.

Applications of Secondary Cells:

- It can be used in fitness bands, smart watches.
- It can be used in military and submarines
- Cameras and artificial pacemakers

The rechargeable or secondary batteries are mainly of three types:

- **Lead Acid**
- **Lithium Ion (Li-ion)**
- **Nickel Metal Hydride (Ni-MH)**
- **Nickel Cadmium (Ni-Cd)**

2. ***Lead Acid -*** Lead acid is a very common type of rechargeable battery. They are generally used to store energy from solar energy because their quality differ them from others. These batteries provides high current, and used in vehicle. When the battery stops working, it can be used for recycling. About 93% of all battery lead is reused for recycle to make new Lead-Acid batteries.

3. ***Lithium Ion (Li-ion)***
   Lithium-ion batteries are rechargeable batteries, also known as Li-ion battery. These batteries are commonly used in electronics as they have great power density. These batteries can store 150 watt-hours per kg. During discharge lithium ions move from the negative electrode to the positive electrode and vice versa. Overheating can cause battery damage or fire.

4. ***Nickel Metal Hydride (Ni-MH)***
   Nickel Metal Hydride batteries are rechargeable batteries. The metal of the battery is inter-metallic. These types of batteries have good life and high current capability. It can store 100 watt-hour per kg. They are more thermally stable than the lithium ion batteries. The self-discharge is higher than the other batteries.

5. ***Nickel Cadmium (Ni-Cd) -*** In Nicker-Cadmium rechargeable battery, Nickel Oxide Hydroxide and Metallic Cadmium are used as electrode. It is also known as NiCd battery or NiCad Battery. Ni-Cd batteries are good to maintain the voltage and hold electric charge when not in use. A major drawback of Ni-Cd battery which may cause lowing the future capacity of battery is that if a partially charge battery is recharged, it may fall a victim of "Dreaded Memory Effect" (i.e. changes in the negative or cadmium plate e.g charging involves converting CD(OH) to Cd metal.) and voltage depression.

Primary Cells	Secondary Cells
Suitable for portable applications due to light weight and smaller design	Not suitable for portable devices
Good charge retention	Inferior charge retention
Not suitable for high cost applications	Highly recommended for backup and high cost applications
Limited to specific applications	Highly versatile and therefore has large spectrum of applications
Low initial cost	Higher initial cost

C] Reserve cell

The reserve batteries or cell are also known as stand-by battery. The electrolyte remains inactive in solid state until the melting point is reached. As soon as the melting point is reached, ionic conduction begins and battery is activated.

Reserve cells are further classified into three categories:

- Water Activated Batteries
- Heat Activated Batteries
- Electrolyte Activated Batteries
- Gas Activated Batteries

Applications of Reserve Batteries:

- It is used in devices used for sensing time and pressure
- They are largely used in weapon systems
- They are also used in car batteries and other vehicles

6. **Fuel cell -** In this class of batteries, active materials are fed from outside source. Fuel cells are capable of producing electrical energy as long as active materials are fed to the electrodes. The proton exchange membrane uses hydrogen and oxygen gas as fuel. The reaction takes place inside the cell and as the product of the reaction water, electricity and heat are produced. The four basic elements of the fuel cells are namely anode, cathode, electrolyte and catalyst.

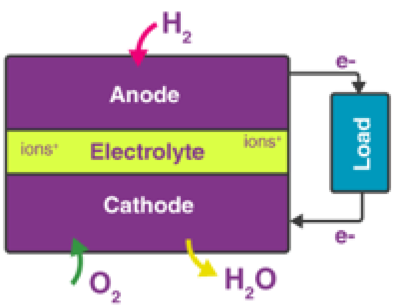
Working of Fuel Cell

The reaction between hydrogen and oxygen can be used to generate electricity via a fuel cell. Such a cell was used in the Apollo space programme and it served two different purposes – It was used as a fuel source as well a source of drinking water (the water vapour produced from the cell, when condensed, was fit for human consumption).

The working of this fuel cell involved the passing of hydrogen and oxygen into a concentrated solution of sodium hydroxide via carbon electrodes. The cell reaction can be written as follows:

- **Cathode Reaction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$**
- **Anode Reaction: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$**
- **Net Cell Reaction: $2H_2 + O_2 \rightarrow 2H_2O$**

However, the reaction rate of this electrochemical reaction is quite low. This issue is overcome with the help of a catalyst such as platinum or palladium. In order to increase the effective surface area, the catalyst is finely divided before being incorporated into the electrodes.



- **Types of Fuel Cells**

1. ***The Polymer Electrolyte Membrane (PEM) Fuel Cell -***
- These cells are also known as proton exchange membrane fuel cells (or PEMFCs).
- The temperature range that these cells operate in is between 50oC to 100oC
- The electrolyte used in PEMFCs is a polymer which has the ability to conduct protons.
- A typical PEM fuel cell consists of bipolar plates, a catalyst, electrodes, and the polymer membrane.
- Despite having eco-friendly applications in transportation, PEMFCs can also be used for the stationary and portable generation of power.

2. ***Phosphoric Acid Fuel Cell -***

- These fuel cells involve the use of phosphoric acid as an electrolyte in order to channel the H+
- The working temperatures of these cells lie in the range of 150oC – 200oC
- Electrons are forced to travel to the cathode via an external circuit because of the non-conductive nature of phosphoric acid.
- Due to the acidic nature of the electrolyte, the components of these cells tend to corrode or oxidize over time.

3. ***Solid Acid Fuel Cell***

- A solid acid material is used as the electrolyte in these fuel cells.
- The molecular structures of these solid acids are ordered at low temperatures.
- At higher temperatures, a phase transition can occur which leads to a huge increase in conductivity.
- Examples of solid acids include CsHSO4 and CsH2PO4 (cesium hydrogen sulfate and cesium dihydrogen phosphate respectively)

4. ***Alkaline Fuel Cell***

- This was the fuel cell which was used as the primary source of electricity in the Apollo space program.
- In these cells, an aqueous alkaline solution is used to saturate a porous matrix, which is in turn used to separate the electrodes.
- The operating temperatures of these cells are quite low (approximately 90oC).
- These cells are highly efficient. They also produce heat and water along with electricity.

5. ***Solid Oxide Fuel Cell***

- These cells involve the use of a solid oxide or a ceramic electrolyte (such as yttria-stabilized zirconia).
- These fuel cells are highly efficient and have a relatively low cost (theoretical efficiency can even approach 85%).
- The operating temperatures of these cells are very high (lower limit of 600oC, standard operating temperatures lie between 800 and 1000oC).
- Solid oxide fuel cells are limited to stationary applications due to their high operating temperatures.

6. ***Molten Carbonate Fuel Cell -***

- The electrolyte used in these cells is lithium potassium carbonate salt. This salt becomes liquid at high temperatures, enabling the movement of carbonate ions.
- Similar to SOFCs, these fuel cells also have a relatively high operating temperature of 650oC
- The anode and the cathode of this cell are vulnerable to corrosion due to the high operating temperature and the presence of the carbonate electrolyte.
- These cells can be powered by carbon-based fuels such as natural gas and biogas.

Applications of fuel cell

- Fuel cell electric vehicles, or FCEVs, use clean fuels and are therefore more eco-friendly than internal combustion engine-based vehicles.
- They have been used to power many space expeditions including the Appolo space program.
- Generally, the byproducts produced from these cells are heat and water.
- The portability of some fuel cells is extremely useful in some military applications.
- These electrochemical cells can also be used to power several electronic devices.
- Fuel cells are also used as primary or backup sources of electricity in many remote areas.

BATTERY PARAMETERS

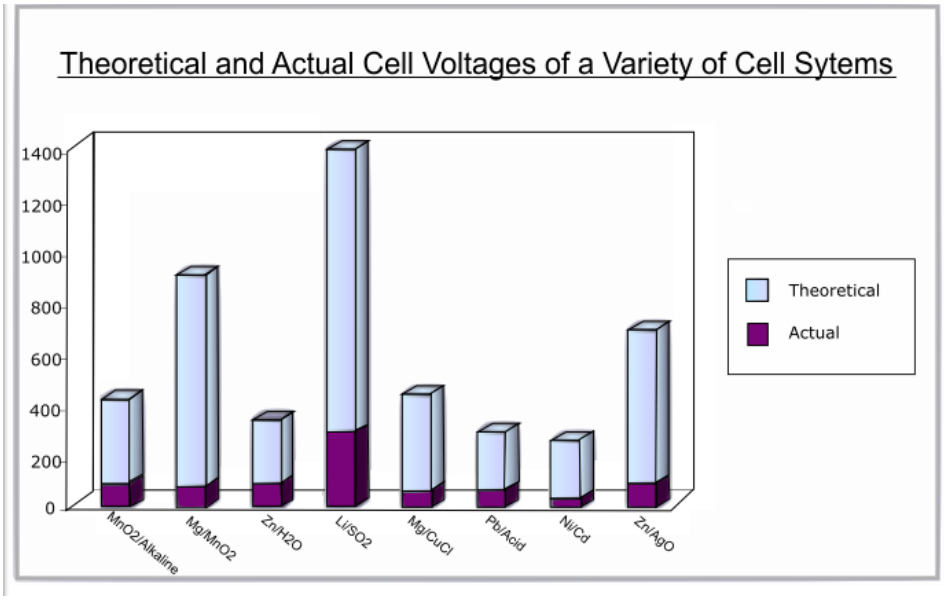
1. ***Voltage -T*** he theoretical standard cell voltage can be determined from the electrochemical series using Eo values:

Eo (cathodic) – Eo (anodic) = Eo (cell)

This is the standard theoretical voltage. The theoretical cell voltage is modified by the Nernst equation, which takes into account the non-standard state of the reacting component. The Nernstian potential will change with time either because of use or self-discharge by which the activity (or concentration) of the electro-active component in the cell is modified. Thus the nominal voltage is determined by the cell chemistry at any given point of time.

The actual voltage produce will always be lower than the theoretical voltage due to polarisation and the resistance losses (IR drop) of the battery and is dependent upon the load current and the internal impedance of the cell. These factors are dependent upon electrode kinetics and thus vary with temperature, state of charge, and with the age of the cell. The actual voltage appearing at the terminal needs to be sufficient for the intended application.

Typical values of voltage range from 1.2 V for a Ni/Cd battery to 3.7 V for a Li/ion battery***.***



2. ***Capacity -*** he theoretical capacity of a battery is the quantity of electricity involved in the electro-chemical reaction. It is denoted Q and is given by:

$$Q = xnF$$

where x = number of moles of reaction, n = number of electrons transferred per mole of reaction and F = Faraday's constant

The capacity is usually given in terms of mass, not the number of moles:

$$Q = \frac{nF}{M_r}$$

where Mr = Molecular Mass. This gives the capacity in units of Ampere-hours per gram (Ah/g).

3. ***Energy density*** -The energy density is the energy that can be derived peer unit volume of the weight of the cell.

4. ***Specific energy density -*** The specific energy density is the energy that can be derived per unit weight of the cell (or sometimes per unit weight of the active electrode material). It is the product of the specific capacity and the operating voltage in one full discharge cycle. Both the current and the voltage may vary within a discharge cycle and thus the specific energy derived is calculated by integrating the product of current and voltage over time. The discharge time is related to the maximum and minimum voltage threshold and is dependent upon the state of availability of the active materials and/or the avoidance of an irreversible state for a rechargeable battery.

5. ***Power density -*** The power density is the power that can be derived per unit weight of the cell (W/kg).

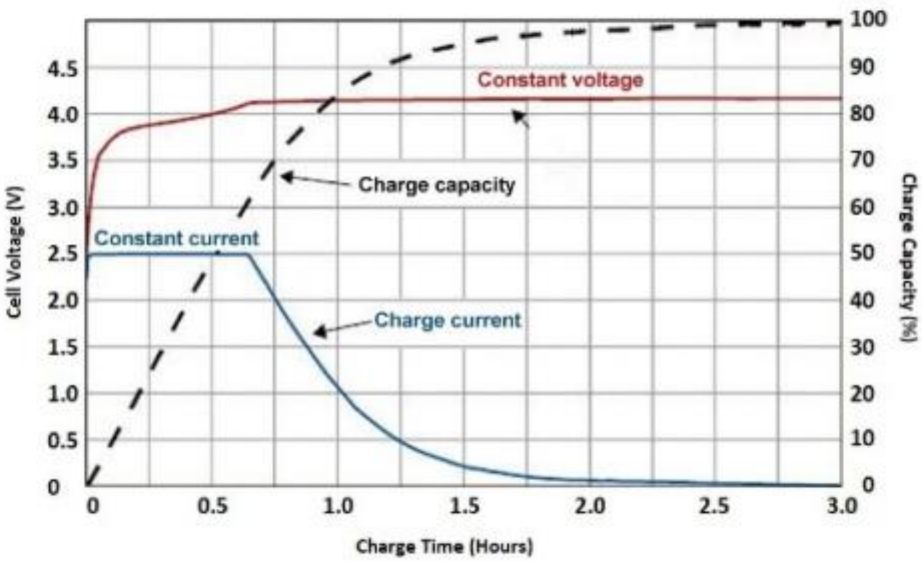
6. ***C rating*** -A battery's C rating measures how quickly it can be discharged. It's calculated by dividing the battery's capacity by the discharge current. For example, a battery with a capacity of 100Ah and a C rating of 1C can be discharged at a rate of 100 amps for one hour

Discharge current - The discharge current limit (DCL) represents the maximum current that can be drawn from a battery pack without causing damage. It is measured in amps and ensures that the system ratings are not exceeded(hence, charge and discharge current)

7. ***State of Charge*** - State of charge refers to the current level of energy stored in a battery or an electrical energy storage system. It is usually expressed as a percentage and indicates how much of the total energy capacity is available for use.

8. ***Depth of Discharge*** - Depth of discharge (DoD) is a term used in the context of batteries, particularly rechargeable batteries. It represents the percentage of a battery's capacity that has been discharged relative to its total capacity.

9. ***Discharge/charge curve***



10. ***Battery efficiency*** - Battery efficiency is a measure of how effectively a battery can convert input energy during charging into output energy during discharging, considering losses in the entire discharge/recharge cycle. It is expressed as a percentage, representing the ratio of energy extracted from the battery compared to the energy input.

11. ***Cycle lifetime*** - Cycle lifetime refers to the number of charge and discharge cycles that a rechargeable battery can undergo before experiencing a significant reduction in its capacity. It is a crucial factor in determining the overall lifespan and durability of a battery. Each complete charge and discharge cycle contribute to the wear and tear of the battery, impacting its ability to hold a charge over time.

Temperature effects - Temperature plays a significant role in influencing the performance and longevity of batteries. Both high and low temperatures can impact a battery's efficiency, capacity, and overall lifespan.

Here's a breakdown of how temperature affects batteries:

- **Capacity**: Temperature has a direct effect on a battery's capacity. Cold temperatures can reduce a battery's capacity temporarily, meaning it can provide less energy than it would at higher temperatures. On the other hand, high temperatures can increase the self-discharge rate, reducing the overall capacity over time.

- **Chemical Reactions**: Battery chemistry is temperature-sensitive. Extreme temperatures can alter the chemical reactions within a battery, affecting its ability to store and deliver energy. High temperatures can accelerate chemical reactions, potentially leading to faster degradation.

- **Internal Resistance**: Temperature impacts the internal resistance of a battery. Higher temperatures generally result in lower internal resistance, allowing for better performance. However, excessively high temperatures can contribute to accelerated aging and reduced cycle life.

- **Lifespan**: Prolonged exposure to high temperatures can significantly shorten the lifespan of a battery. For example, in electric vehicle batteries, consistently operating in high-temperature environments can lead to a faster degradation of capacity over time.

- **Charging Efficiency**: Charging a battery in extreme temperatures can be less efficient and, in some cases, unsafe. High temperatures can lead to overheating during charging, while low temperatures can slow down the charging process.

12. ***Memory effect*** -Memory effect occurs when a battery appears to "remember" its previous level of discharge and does not provide its full capacity. This is often associated with repetitive shallow discharges, where the battery is not fully discharged before being recharged.

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