PROJECT REPORT

On

ELECTROCHEMICAL CELLS and BATTERY ADVANCEMENTS

Submitted by

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CERTIFICATE

This is to certify that **S.J.EBEN GORKY** (Reg.No:) of class XII - science, **Geethaanjali All India Senior Secondary School, Thindal, Erode**, has successfully completed his project in chemistry on the topic of **ELECTROCHEMICAL CELLS and BATTERY ADVANCEMENTS** of **AISSCE** as prescribed by CBSC in the year 2023-2024.

Viva voice held on :

Registration no :

Signature of the guide **Signature of the Principal**

Signature of the Internal Examiner **Signature of the External Examiner**

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INTRODUCTION

Electrochemical cells serve as the unseen powerhouses behind many modern conveniences, seamlessly converting chemical energy into electrical energy. Operating on the principles of redox reactions, electrochemical cells enable the controlled flow of electrons between two electrodes, generating a useful electric current. This fundamental concept is at the core of diverse applications, from the batteries in our electronic gadgets to the propulsion systems of electric vehicles and the storage of renewable energy.

These cells are broadly categorized into galvanic (voltaic) cells, where spontaneous chemical reactions produce electrical energy, and electrolytic cells, which consume electrical energy to drive non-spontaneous reactions. The magic of electrochemistry unfolds through these cells, driving technological advancements and sustainable energy solutions.

The landscape of battery technology is experiencing a revolutionary metamorphosis, driven by an insatiable appetite for more powerful, efficient, and environmentally friendly energy storage solutions. In this era of rapid innovation, battery advancements have transcended the confines of traditional limitations, ushering in a new era of portable power and sustainable energy.

Lithium-ion batteries stand as the stalwarts of modern energy storage. Their remarkable energy density, coupled with lightweight design, has made them the go-to choice for an array of applications, from powering smartphones to propelling electric vehicles. The ongoing refinement of lithium-ion technology continues to elevate performance benchmarks.

The quest for safer and higher-performing batteries has led to the rise of solid-state battery technology. By replacing the liquid electrolyte with a solid alternative, these batteries offer improved safety, higher energy density, and extended lifespan. Researchers are tirelessly working to bring solid-state batteries into mainstream applications.

The heart of any battery lies in its materials, and recent breakthroughs in anode and cathode materials are shaping the future of energy storage. Innovations like silicon anodes and lithium-metal cathodes promise increased energy storage capacities, pushing the boundaries of what batteries can achieve.

Flowing Towards the Future: Flow batteries are emerging as a compelling solution for large-scale energy storage. Their unique design involves storing liquid electrolytes in external tanks, allowing for scalability and efficient integration with renewable energy sources. This makes flow batteries a promising contender for grid-level energy storage.

Batteries of the future might possess a degree of self-healing capability. Through the integration of self-repairing materials, researchers aim to enhance the durability and longevity of batteries, addressing one of the key challenges in energy storage.

THEORY OF VOLTA’S

Alessandro Volta's contact theory is foundational to his invention of the voltaic pile, the precursor to modern electrochemical cells. Volta's work, conducted at the turn of the 19th century, challenged the prevailing theory proposed by Luigi Galvani, which suggested that the generation of electricity in animals (like frogs) was due to the presence of an "animal electricity" intrinsic to living organisms.

Volta, through systematic experimentation, proposed an alternative explanation based on the concept of contact electricity. He argued that the key to generating electricity was not the inherent properties of living organisms but rather the contact between dissimilar metals. Volta discovered that when two different metals come into contact and are separated by an electrolyte (a substance that conducts electricity when dissolved in a solvent), an electric current is generated.

The voltaic pile, invented by Volta in 1800, embodied his contact theory. The pile consisted of alternating discs of two different metals, such as zinc and copper, separated by a moistened cardboard or cloth soaked in an electrolyte solution. The specific metals and electrolyte used were crucial in determining the voltage produced by the pile.

Volta's contact theory marked a significant shift in understanding the nature of electricity, emphasizing the role of material composition and contact between dissimilar substances in the generation of electric potential. This ground-breaking work laid the foundation for the development of batteries and electrochemical cells, which have since become integral to various technological applications, from portable electronics to electric vehicles. Volta's contributions earned him recognition and led to the naming of the unit of electric potential, the volt, in his honour.

EXPERIMENT-1

Voltaic pile

Aim:-

To produce current through stack of small current cells.

Materials required:-

- Copper plates (coin size).
- Zinc plates (coin size).
- Thin cardboard or paper.
- Non conducting plate

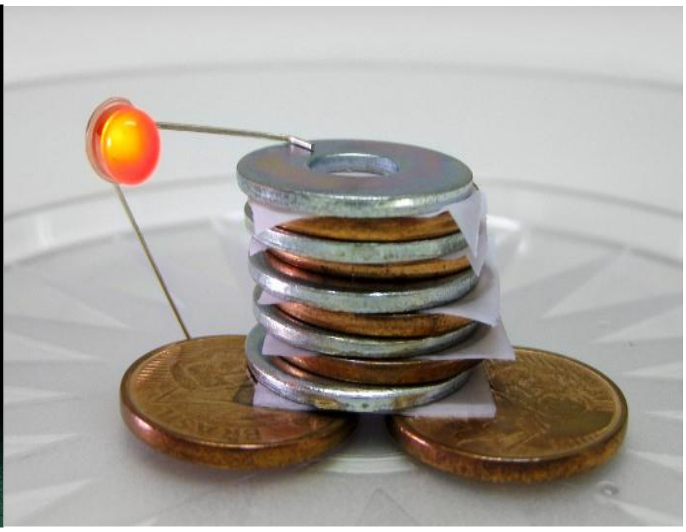
Procedures:-

- cut cardboard to size of the paper
- Prepare electrolyte by mixing vinegar and salt.
- Place the copper coin on the non-conducting plate.

- Dip the cutted paper into the solution and place it on the copper Plate.
- Place the zinc plate on the top of paper sold with electrolyte.
- Again place the copper plate on top of zinc plate and repeat the process.
- After the several times, take a bulb and connect it's both ends to the plates of zinc and copper plates respectively of the pile.

Observation

- The bulb glow on the flow of current

REDOX REACTIONS OF CELLS

1. Oxidation Half-Reaction:

- At the anode (negative electrode), oxidation occurs. This is where the substance being oxidized loses electrons.
- Example: In a zinc-copper electrochemical cell, the oxidation half-reaction might be: Zn(s) →Zn_2+ (aq) +2e
- In this example, zinc (Zn) is oxidized to form zinc ions (Zn^{2+}) and releases two electrons.

2. Reduction Half-Reaction:

- At the cathode (positive electrode), reduction occurs. This is where the substance being reduced gains electrons.

- Example: In the same zinc-copper electrochemical cell, the reduction half-reaction might be: Cu_2+ (aq) $+2e^{-} \rightarrow Cu(s)$

- Here, copper ions (Cu^{2+}) gain two electrons and are reduced to form solid copper.

3. Complete Redox Reaction:

- The overall redox reaction is the combination of the oxidation and reduction half-reactions. For the zinc-copper cell: $Zn(s)+Cu_2+(aq) \rightarrow Zn_2+(aq)+Cu(s)$

- Electrons released during the oxidation of zinc at the anode travel through the external circuit to the copper ions at the cathode, where they are accepted during the reduction of copper.

4. Electron Flow and Current:

- Electrons flow from the anode to the cathode through an external circuit, creating an electric current.

- The salt bridge or ion-conductive membrane allows the migration of ions between the two half-cells, maintaining charge balance.

5. Electrochemical Cell Representation:

- The electrochemical cell is often represented using a cell notation. For the zinc-copper cell, the notation would be: $Zn(s) \,|Zn_2+ (aq)\, ||Cu_2+ (aq)\, |Cu(s)$

OTHER REDOX REACTIONS OF CELLS

1. Galvanic Cell (Voltaic Cell) - Zinc-Copper Cell:

- Oxidation Half-Reaction (Anode):

$$Zn(s) \rightarrow Zn2+ (aq) +2e$$

- Reduction Half-Reaction (Cathode):

$$Cu2+ (aq) +2e- \rightarrow Cu(s)$$

- Complete Redox Reaction:

$$Zn(s) +Cu2+ (aq) \rightarrow Zn2+ (aq) +Cu(s)$$

2. Daniell Cell - Copper-Zinc Cell:

- Oxidation Half-Reaction (Anode):

$$Zn(s) \rightarrow Zn2+ (aq) +2e$$

- Reduction Half-Reaction (Cathode):

$$Cu2+ (aq) +2e- \rightarrow Cu(s)$$

- Complete Redox Reaction:

$$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$$

3. Electrolysis of Water:

- Oxidation Half-Reaction (Anode):

$$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$$

- Reduction Half-Reaction (Cathode):

$$4H_2O(l) + 4e^- \rightarrow 2H_2(g) + 4OH^-(aq)$$

- Complete Redox Reaction:

$$2H_2O(l) \rightarrow O_2(g) + 2H_2(g)$$

EXPERIMENT-2

Aim:

To show different E_{Cell} value for a cell in its entire range of concentration.

Materials required:

- Galvanic cell
- Low Resistive Volt metre
- Graph sheet

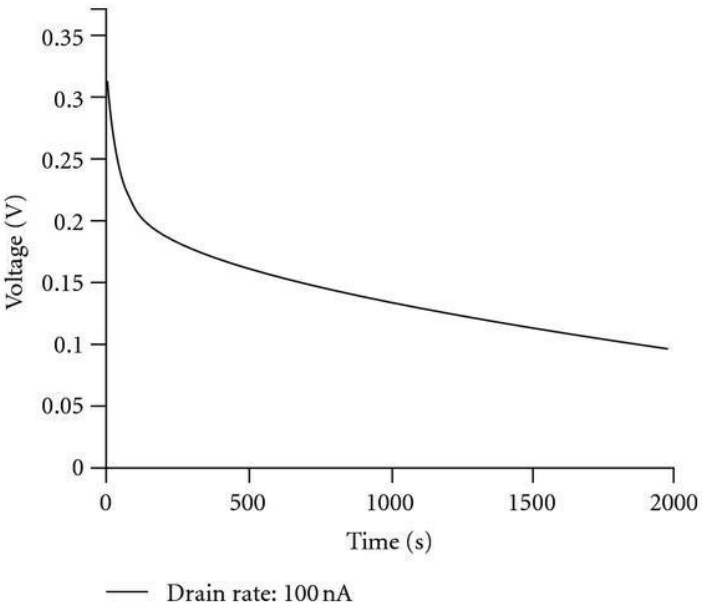
Procedure:

- Set up the galvanic cell to give current of any load through a key to drain the battery.
- Connect a low resistive volt meter to battery or parallel to load
- Measure its potential difference across electrode.
- Mark in graph.

- Use the key to drain the battery for a while.
- Again measure its potential across electrode.
- Repeat this process until the battery dies.

Observation:

The obtained graph is not linear which means the voltage across the electrode varies which repeat to concentration of electrode.



DERIVING NERNST EQUATION USING GIPS ENERGY

Energy of ideal cell (with no loss in potential energy)

$$\Delta g^\circ = -RTln(k)$$

$$\Delta g^\circ = -nfE^\circ_{cell}$$

Energy of cell with loss in potential energy

$$\Delta g = \Delta g^\circ + RTln(k)$$

$$\Delta g = -nfE_{cell}$$

Equating these two:

$$-nfE_{cell} = -nfE^\circ_{cell} + RTln[k]$$

Since k in changing in all values of E k = [m]/ [m^{n+}]

$$E_{cell} = E^\circ_{cell} - \frac{RT}{nf} ln[\frac{[\mathrm{m}]}{[m^{n+}]}]$$

$$E_{cell} = E^\circ_{cell} - \frac{2.303RT}{nf} log[\frac{[\mathrm{m}]}{[m^{n+}]}]$$

THE ADVANCEMENTS DONE IN LITHIUM ION BATTERY

Cathode Material Innovations:

Transition Metal Oxides: Advancements in high-energy-density cathode materials, such as nickel-rich lithium nickel cobalt manganese oxide (NCM) and lithium nickel cobalt aluminium oxide (NCA), have increased the energy density of LIBs.

Layered Oxides: Materials like lithium nickel manganese cobalt oxide (NMC) with varying metal ratios improve stability and cycle life.

Anode Material Developments:

Silicon Anodes: Silicon anodes have been explored due to their high theoretical capacity, leading to increased energy density. Nano structuring and composite materials help mitigate the volume expansion issues associated with silicon.

Graphite Innovations: Improvements in artificial graphite and graphite-silicon composites contribute to enhanced energy storage and cycling stability.

Solid-State Electrolytes:

Advancements: Solid-state electrolytes, replacing traditional liquid electrolytes, offer improved safety, higher energy density, and wider operating temperature ranges.

Impact: Solid-state electrolytes mitigate safety concerns related to dendrite growth and thermal instability, making LIBs safer for various applications.

Advanced Manufacturing Techniques:

Roll-to-Roll Production: Continuous manufacturing processes like roll-to-roll have increased production efficiency and reduced costs.

Precision Coating and Drying: Advanced coating and drying techniques ensure uniform electrode structures, enhancing the overall performance of LIBs.

Smart Battery Management Systems (BMS):

Advancements: Advanced BMS technologies monitor and manage individual cells, optimizing charging and discharging cycles.

Impact: BMS improves safety, prolongs battery life, and enhances overall performance by preventing issues such as overcharging and over-discharging.

High-Nickel Cathodes:

Advancements: Cathodes with higher nickel content, such as NMC 811 (8 parts nickel, 1 part manganese, 1 part cobalt), offer increased energy density.

Impact:

LIBs with high-nickel cathodes deliver better performance and energy storage capacity.

Next-Generation Anode Materials:

Silicon Carbide (SiC) Coating: SiC coatings on graphite anodes improve stability and capacity retention.

Lithium Titanate ($Li_4Ti_5O_{12}$): $Li_4Ti_5O_{12}$ anodes offer high cycling stability and fast charging capabilities.

Recycling and Sustainability:

Advancements: Developing efficient recycling processes for LIBs addresses environmental concerns and promotes a circular economy.

Impact: Improved recycling methods help recover valuable materials, reduce environmental impact, and contribute to sustainable battery production.

Flexible and Thin-Film Batteries:

Advancements: Research in flexible and thin-film LIBs enables their integration into wearable devices and flexible electronics.

Impact:

These batteries offer new design possibilities and applications in areas such as electronic textiles and medical devices.

THE ADVANCEMENTS DONE IN NICKEL CADMIUM BATTERY

Cadmium-Free Formulations:

Advancements: Ongoing research focuses on reducing or eliminating cadmium in Ni-Cd batteries due to environmental concerns associated with cadmium toxicity.

Impact: Cadmium-free Ni-Cd formulations aim to enhance the sustainability and eco-friendliness of these batteries.

High-Capacity Electrodes:

Advancements: Improved electrode materials, including high-capacity cathodes, have been developed to increase the energy density of Ni-Cd batteries.

Impact: Higher capacity electrodes contribute to improved performance and energy storage capabilities.

Improved Electrolyte Formulations:

Advancements: Advances in electrolyte formulations aim to enhance the overall efficiency and cycle life of Ni-Cd batteries.

Impact: Improved electrolytes contribute to better charge/discharge characteristics, reduced self-discharge rates, and increased reliability.

Memory Effect Mitigation:

Advancements: Research has focused on mitigating the memory effect, a phenomenon where Ni-Cd batteries lose capacity if not fully discharged before recharging.

Impact: Efforts to minimize memory effects contribute to maintaining the capacity and performance of Ni-Cd batteries over multiple charge cycles.

Rapid Charge/Discharge Capabilities:

Ni-Cd batteries with improved charge and discharge characteristics have been developed for applications requiring rapid energy transfer.

Impact: Enhanced rapid charge/discharge capabilities make Ni-Cd batteries suitable for applications such as power tools and certain portable electronic devices.

Long Cycle Life Formulations:

Advancements: Formulations that extend the cycle life of Ni-Cd batteries have been developed, making them more suitable for applications where long-term reliability is crucial.

Impact: Longer cycle life contributes to reduced maintenance requirements and overall cost-effectiveness.

Sealed Ni-Cd Batteries:

Development of sealed Ni-Cd batteries has improved safety, making them more suitable for applications where leakage is a concern.

Impact: Sealed Ni-Cd batteries find applications in medical devices, emergency lighting, and other critical systems.

Efforts towards Environmental Sustainability:

Advancements: There are ongoing efforts to improve the environmental impact of Ni-Cd batteries, including better recycling technologies.

Impact: Improved recycling methods contribute to the reduction of environmental hazards associated with cadmium, making Ni-Cd batteries more environmentally sustainable.

NEW BATTERY TECHNOLOGY

Sodium ion battery

1. Anode:

Material: Common anode materials for sodium-ion batteries include hard carbon, graphite, and alloying materials (such as tin and antimony).

Sodium Intercalation: During discharge, sodium ions are extracted from the anode material, and the anode undergoes a reversible sodium ion intercalation process.

2. Cathode:

Material: Various cathode materials have been explored, including transition metal oxides (such as $NaFeO_2$, $Na_2Fe_2(SO_4)_3$, and Prussian blue analogs), polyanionic compounds, and organic compounds.

Sodium Deintercalation:

During discharge, sodium ions are inserted into the cathode material, and the cathode undergoes a reversible sodium ion deintercalation process.

3. Electrolyte:

Type: Sodium-ion batteries typically use a liquid electrolyte, often based on a sodium salt dissolved in a suitable solvent. Solid-state electrolytes are also being researched for potential application in NIBs.

Function: The electrolyte facilitates the transport of sodium ions between the anode and cathode during charging and discharging.

4. Working Mechanism:

Charging: During charging, sodium ions are extracted from the anode and move through the electrolyte to the cathode, where they are inserted into the cathode material.

Discharging: During discharging, the process is reversed, with sodium ions moving from the cathode to the anode.

5. Advantages:

Abundance of Sodium: Sodium is more abundant and less expensive than lithium, potentially making sodium-ion batteries more cost-effective.

Compatibility with Existing Infrastructure: NIBs are seen as a potential option for large-scale energy storage due to their compatibility with existing lithium-ion battery manufacturing infrastructure.

6. Challenges:

Lower Energy Density: Sodium-ion batteries generally have lower energy density compared to lithium-ion batteries, limiting their application in certain portable electronic devices.

Cycling Stability: Maintaining good cycling stability over a large number of charge-discharge cycles remains a challenge.

Development Stage: While research is ongoing, commercialization and widespread adoption of sodium-ion batteries are still in the early stages compared to lithium-ion batteries.

7. Applications:

Grid Energy Storage: Sodium-ion batteries are being explored for large-scale grid energy storage applications, where their cost-effectiveness and abundance of sodium resources make them attractive.

Electric Vehicles: While not as common as lithium-ion batteries for electric vehicles, sodium-ion batteries are being researched for potential use in this application.

CONCLUSION

Electrochemical cells are devices that convert chemical energy into electrical energy through redox reactions. These cells are essential in powering everyday devices and have widespread applications, ranging from small batteries in electronic devices to large-scale energy storage solutions. The key principles involve the movement of electrons through an external circuit and ions through an electrolyte.

Recent advancements in battery technology have focused on improving energy density, materials innovation, fast-charging capabilities, and grid storage. Higher energy density enables longer-lasting and more powerful batteries, while innovations in materials, such as solid-state electrolytes, contribute to improved performance and safety. Fast-charging technologies address the need for quick recharging, enhancing the convenience of electronic devices and electric vehicles.

Additionally, advancements in grid storage support the integration of renewable energy sources into the power grid.

Despite these advancements, challenges persist, including cost, resource availability, and safety concerns. Ongoing research and development aim to address these challenges, presenting opportunities for further innovation in electrochemical cell technologies. Overall, these advancements contribute to a more sustainable and efficient use of energy in various sectors, shaping the future of power storage and consumption.

BIBLIOGRAPHY

- https://www.electrochem.org/birth-of-electrochemistry/
- https://www.aps.org/publications/apsnews/200603/history.cfm
- https://nationalmaglab.org/magnet-academy/history-of-electricity-magnetism/museum/voltaic-pile/
- https://byjus.com/jee/nernst-equation/
- https://www.technologyreview.com/2023/01/04/1066141/whats-next-for-batteries/
- https://en.wikipedia.org/wiki/Sodium-ion_battery