

ELECTROCHEMISTRY

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Electrochemistry is the branch of physical chemistry which studies the relationship between electrical and chemical phenomenon and laws of their interaction.

Two types of processes are involved:

- ① Electrolytic process: electroplating with Ag, and refining of metals
- ② Electrochemical process: electricity is produced due to chemical reactions.

Standard Electrode Potential

It is the measure of tendency of an electrode either to lose electron or to gain electron (reduction potential) (oxidation potential)

when it is in its own salt solution of 1 M concentration at 25°C

Under the above mentioned conditions, the metal has a tendency to undergo oxidation and reduction which results into formation of layers of negative and positive charges known as (Helmholtz electrical double layer) due to this a potential difference is developed between metal and solution which becomes constant at equilibrium and is known as standard electrode potential.

Measurement of E° : (Standard Electrode Potential)

$[Pt|H_2(g)|H^+(aq)]$ (Structure of SHE)

Electrochemical Series & Its Importance

- Predicting whether a metal can liberate Hydrogen gas from acids or not.
- Predicting Anode & Cathode
- Calculation of emf of the cell

$$E_{\text{cell}} = (\text{Standard reduction potential of cathode}) - (\text{Standard reduction potential of anode})$$
- $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$
- Predicting Oxidising and Reducing Ability
- Predicting Replacement tendency
- (Key point for these predictions) -

Lower Reduction potential:- Anode, replace other metals from their salts, better reducing ability
 Metals have negative E° Red can liberate hydrogen from acids).

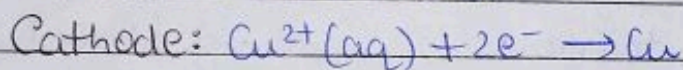
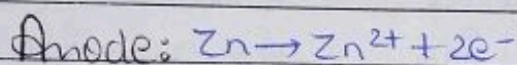
NERNST EQUATION: $aA + bB \rightarrow cC + dD$

$$E_{\text{cell}} = E^{\circ}_{\text{cell}} - \frac{2.303RT}{nF} \log \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

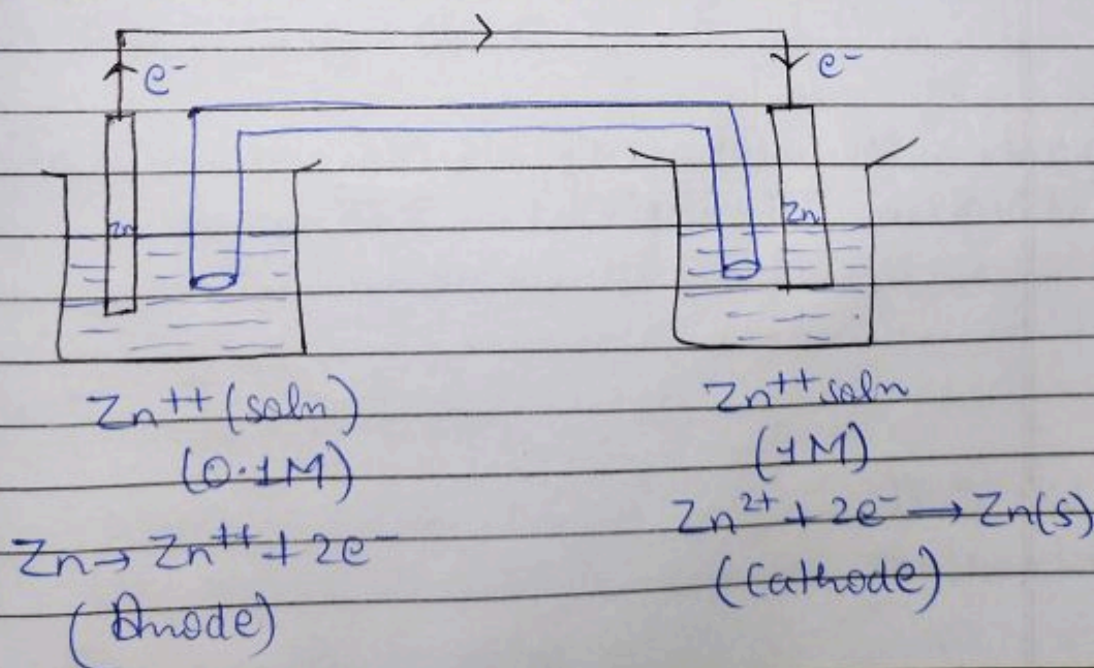
$$E_{\text{cell}} = E^{\circ}_{\text{cell}} - \frac{0.0591}{n} \log \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

Electrochemical Cell: It is a device which converts chemical energy into electrical energy. It is of two types:-

① Chemical cells: where emf arises due to chemical reactions occurring in cell.
eg. galvanic cell, voltaic cell



② Concentration cell: emf arises due to transfer of substance from a system of high concentration to low concentration.



Difference between Electrochemical and Electrolytic Cell

Electrochemical Cell

- Converts chemical energy to electrical energy
- Cathode is positive electrode and anode is negative electrode
- Spontaneous Reaction occurs
- In electrochemical cell, half cells are placed in different containers and connected by a salt bridge.

Electrolytic Cell

- Converts electrical to chemical energy
- Cathode is negative electrode and anode is positive electrode
- Non spontaneous Rxn occurs
- Electrodes are placed in a similar container and placed in an electrolytic solution.

GREEN BATTERIES

&

their Applications

Green battery refers to environmentally friendly energy storage solutions designed to reduce environmental impact.

They typically use sustainable materials and processes, aiming for lower toxicity and better recyclability compared to traditional batteries.

A green battery is first a battery that stores "green" electrons those generated by renewable resources such as wind or solar.

Various Classes of Green Battery

① Lithium-Ion Batteries (with sustainable practices)

Description: While traditional lithium-ion batteries have environmental concerns, improvements in mining practices and recycling technologies are making them greener.

Application: Electric Vehicles (EVs), renewable energy storage, consumer electronics and grid stabilization.

② Sodium-Ion Batteries

Description: Made from abundant sodium, it is cost effective and sustainable as compared to lithium-ion battery.

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Application: Similar to lithium-ion battery.

③ Solid-State Batteries

Electrolyte is in solid form, gives safety and energy density.

Application: In EV and portable devices, longer lifespan and quicker charging.

④ Biodegradable Battery

Made from biodegradable material.

Application: Consumer electronics, medical devices, IoT devices where short term use is required.

Application of Green Batteries x

① EVs: reducing reliance on fossil fuels and lowering greenhouse gas emissions. Advances in sodium ion and solid state technologies.

② Renewable Energy Storage: Particularly, flow batteries and lithium ion batteries, store excess energy generated from renewable sources like solar, wind, helping to balance supply and demand on the grid.

- ③ Consumer Electronics: Laptops, smartphones and other devices benefit from advances in lithium-ion and organic batteries with a focus on improved recyclability and sustainable source of materials.
- ④ Grid Stabilization: Large scale battery systems help maintain grid stability by storing energy during low demand and releasing it during peak demand.
- ⑤ Off-Grid Systems: Green batteries are ideal for remote or off-grid applications, providing reliable energy storage for homes and businesses powered by renewable sources.
- ⑥ Medical devices: Biodegradable and organic batteries offer safe and sustainable options for medical devices that require short term energy solutions.
- ⑦ Wearable Technology: Light weight and efficient green batteries can enhance the performance and sustainability of wearable tech, such as fitness trackers and smartwatches.

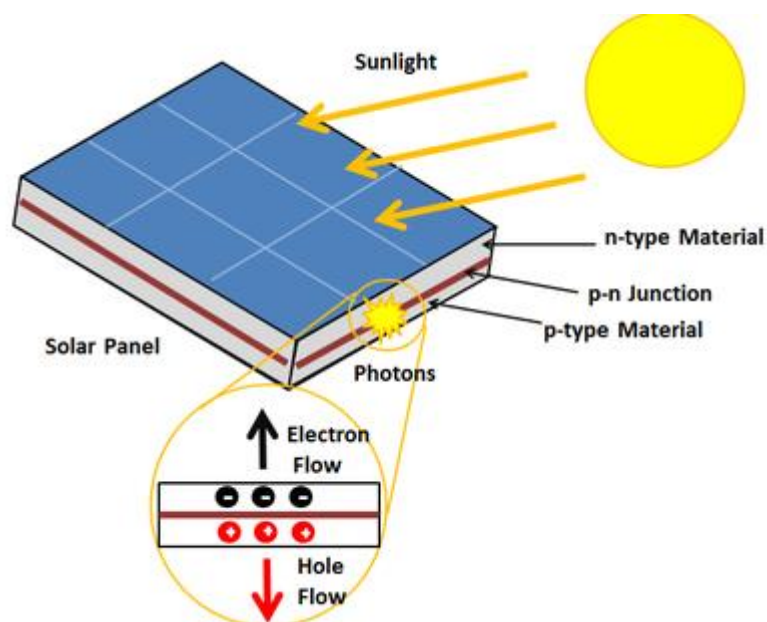
Unit 2 Eco-friendly Portable Energy Convertible Devices

2.2. Photovoltaic cell

A photovoltaic (PV) cell is a device that converts sunlight directly into electricity through the photovoltaic effect. Here's a breakdown of how it works and its key components:

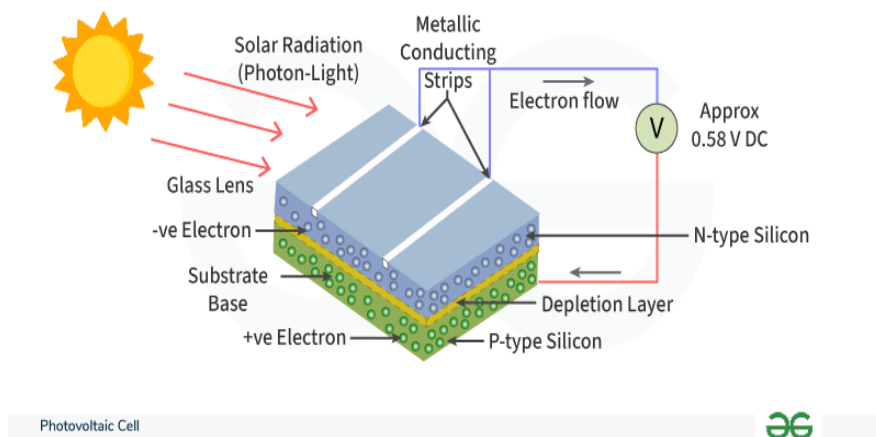
How It Works

1. **Photons and Absorption:** When sunlight (photons) hits the PV cell, it can be absorbed by the semiconductor material, typically silicon.
2. **Electron Excitation:** The energy from the absorbed photons excites electrons in the semiconductor, knocking them loose from their atoms.
3. **Electric Field Creation:** The structure of the PV cell creates an electric field that directs these free electrons towards metal conductive plates, generating an electric current.
4. **Current Flow:** The flow of electrons can be harnessed as electricity, which can then be used to power electrical devices or fed into the electrical grid.



Key Components

- **Semiconductor Material:** Silicon is the most common, but other materials like cadmium telluride and gallium arsenide are also used.
- **Front and Back Contacts:** These metal layers collect and transport the electric current generated.
- **Anti-Reflective Coating:** This layer minimizes reflection and maximizes light absorption.
- **Glass Cover:** Protects the cell from environmental damage while allowing light to pass through.



2.2.1. Properties of Solar grade Silicon

Solar-grade silicon has specific properties that make it suitable for use in photovoltaic cells. Here are the key properties:

1. High Purity

- **Purity Level:** Solar-grade silicon typically has a purity of 99.9999% (6N). This high level of purity is crucial for efficient electron movement, which enhances the cell's performance.

2. Crystalline Structure

- **Types:** Solar-grade silicon can be either monocrystalline or multicrystalline:

- **Monocrystalline Silicon:** Features a single crystal structure, which allows for higher efficiency and better performance in low-light conditions.
- **Multicrystalline Silicon:** Composed of multiple crystal structures, generally less efficient than monocrystalline but more cost-effective to produce.

3. Band Gap

- **Energy Band Gap:** The band gap of silicon is approximately 1.1 eV (electron volts), which is ideal for absorbing a wide range of solar radiation, allowing it to convert sunlight into electricity effectively.

4. Electrical Conductivity

- **N-type and P-type:** Silicon can be doped with elements like phosphorus (N-type) or boron (P-type) to create p-n junctions, essential for creating the electric field in solar cells.

5. Thermal Stability

- **High Melting Point:** Silicon has a high melting point (around 1,410°C), making it stable and durable under various environmental conditions.

6. Mechanical Strength

- **Durability:** Silicon wafers possess sufficient mechanical strength to withstand handling and integration into solar modules.

7. Light Absorption

- **Optical Properties:** Solar-grade silicon has favorable light absorption characteristics, allowing it to capture a significant portion of the solar spectrum.

8. Low Temperature Coefficient

- **Efficiency Stability:** Silicon solar cells have a relatively low temperature coefficient, meaning their efficiency doesn't drop significantly with increasing temperatures compared to other materials.

9. Chemical Stability

- **Resistance to Environmental Factors:** Silicon is chemically stable, which helps in maintaining performance over time when exposed to outdoor conditions.

Conclusion

These properties collectively make solar-grade silicon an optimal material for photovoltaic applications, enabling effective energy conversion and long-term durability in solar cells.

2.2.2. Production of Solar grade Silicon

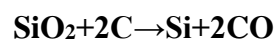
The production of solar-grade silicon is a critical process for manufacturing photovoltaic cells. Here's an overview of how it's done:

1. Raw Material Sourcing

- **Silica (SiO₂):** The primary raw material is silica, typically sourced from quartz sand. It must be of high purity to minimize impurities in the final silicon product.

2. Metallurgical Silicon Production

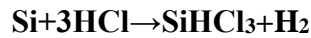
- **Reduction Process:** Silica is mixed with carbon (usually in the form of coal or coke) and heated in a furnace at temperatures around 1,500°C. This process reduces the silica to metallurgical silicon (98-99% purity) through a chemical reaction:



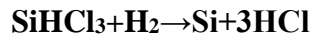
3. Purification to Solar-Grade Silicon

- **Chemical Purification:** The metallurgical silicon is then purified to reach solar-grade silicon (99.9999% purity or 6N silicon). Two common methods are:

- **Siemens Process:** Involves converting metallurgical silicon into trichlorosilane (SiHCl_3) by reacting it with hydrogen chloride:



The trichlorosilane is then purified through distillation and reacted with hydrogen to produce high-purity silicon:



- **Fluidized Bed Reactor Process:** A newer method that uses a fluidized bed to reduce silicon at lower temperatures, allowing for a more energy-efficient and cost-effective production.

4. Crystal Growth

- **Czochralski Method:** The purified silicon is melted and then crystallized into single or multicrystalline forms, often using the Czochralski method. This involves slowly pulling a seed crystal from the molten silicon to create a large ingot.

5. Wafer Production

- **Slicing:** The silicon ingots are then sliced into thin wafers using diamond wire saws. These wafers serve as the substrate for solar cells.

6. Final Steps

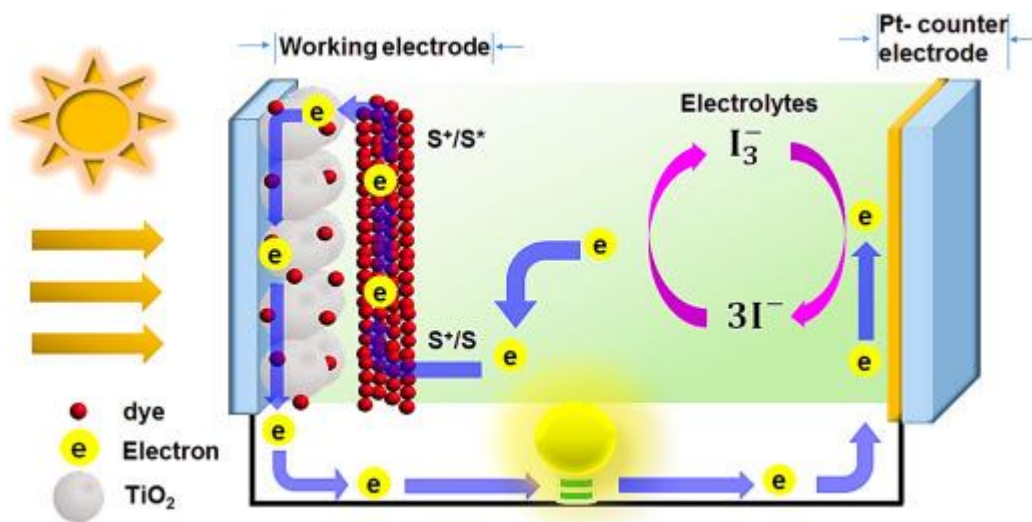
- **Surface Treatment:** The wafers undergo surface treatment to improve light absorption and reduce reflection, often involving an anti-reflective coating.
- **Doping:** The silicon wafers are doped with elements like phosphorus or boron to create p-n junctions, essential for the photovoltaic effect.

Conclusion

The production of solar-grade silicon is a complex process that involves multiple steps to ensure high purity and efficiency for solar cells. Advances in technology continue to improve the methods, reducing costs and environmental impact, making solar energy more accessible.

2.3 Dye-sensitized solar cells (DSSCs)

Dye-sensitized solar cells (DSSCs) are a type of solar cell that uses a photosensitive dye to absorb sunlight and generate electricity. They are known for their unique structure and aesthetic appeal, often seen as a more flexible and potentially lower-cost alternative to traditional silicon-based solar cells. Here's an overview of how they work, their components, advantages, and challenges:



How They Work

1. **Light Absorption:** The process begins when sunlight strikes the dye molecules, which are adsorbed onto a semiconductor material (usually titanium dioxide, TiO_2). The dye absorbs photons and becomes excited.
2. **Electron Injection:** The excited dye molecules inject electrons into the conduction band of the TiO_2 semiconductor.
3. **Electron Transport:** The electrons then travel through the TiO_2 layer toward the transparent conducting electrode (usually made of fluorine-doped tin oxide, FTO).
4. **Redox Reaction:** A liquid electrolyte, typically containing iodide and triiodide ions, is placed in contact with the TiO_2 layer. After the electron is injected into TiO_2 , the

dye becomes oxidized. The electrolyte then donates an electron back to the oxidized dye, regenerating it for further light absorption.

5. **Current Collection:** The electrons collected at the conducting electrode flow through an external circuit, providing electrical power before returning to the electrolyte.

Key Components

- **Dye:** Organic or metal-organic dyes that absorb visible light and are crucial for the cell's efficiency.
- **Semiconductor Layer:** Typically TiO_2 , which provides a structure for electron transport.
- **Electrolyte:** A liquid or gel electrolyte that facilitates the movement of ions, essential for the redox reaction.
- **Conducting Electrodes:** Transparent conductive oxides that allow light to enter while collecting the generated current.

Advantages

- **Cost-Effective:** Generally lower production costs compared to silicon solar cells due to the materials used and simpler manufacturing processes.
- **Aesthetic Flexibility:** DSSCs can be made in various colors and transparency levels, making them suitable for architectural applications.
- **Performance in Low Light:** They perform relatively well in low-light conditions compared to some traditional solar cells.
- **Lightweight and Flexible:** DSSCs can be made on flexible substrates, allowing for new applications in unconventional settings.

Challenges

- **Stability and Durability:** The liquid electrolytes can be prone to leakage and degradation over time, impacting the longevity of the cells.
- **Efficiency:** While DSSCs can achieve reasonable efficiencies (typically around 7-11%), they generally do not reach the efficiency levels of silicon solar cells.
- **Temperature Sensitivity:** Their performance can decrease significantly at higher temperatures.

Conclusion

Dye-sensitized solar cells represent an innovative approach to solar energy conversion, combining aesthetics with potential cost advantages.

2.4 Green Fuel Cells

A green fuel cell is a type of fuel cell that utilizes renewable resources and environmentally friendly processes to generate electricity. Unlike conventional fuel cells that might use fossil fuels, green fuel cells are designed to minimize greenhouse gas emissions and utilize sustainable energy sources. Here's an overview of how they work, their types, benefits, and challenges:

How Green Fuel Cells Work

Fuel cells convert chemical energy directly into electrical energy through an electrochemical reaction. The main components of a fuel cell include:

1. **Anode:** The negative electrode where the fuel (often hydrogen) is introduced.
2. **Cathode:** The positive electrode where oxygen (from air) is introduced.
3. **Electrolyte:** A substance that allows ions to move between the anode and cathode, while preventing the direct flow of electrons.
4. **External Circuit:** Conducts the flow of electrons from the anode to the cathode, generating electricity.

Types of Green Fuel Cells

1. **Proton Exchange Membrane Fuel Cells (PEMFCs):** Often use hydrogen produced from renewable sources (like electrolysis of water using solar or wind energy) and operate at relatively low temperatures.
2. **Solid Oxide Fuel Cells (SOFCs):** Can use a variety of fuels, including biogas, and operate at high temperatures. They are known for high efficiency but can be more complex and expensive.
3. **Alkaline Fuel Cells (AFCs):** Utilize alkaline electrolytes and can also operate with hydrogen, making them suitable for applications that focus on green hydrogen.

4. **Direct Methanol Fuel Cells (DMFCs):** Use methanol as a fuel, which can be derived from biomass, offering a potential renewable source.

Benefits

- **Sustainability:** By using renewable fuels like hydrogen from electrolysis or biogas, green fuel cells can significantly reduce carbon footprints.
- **High Efficiency:** Fuel cells generally have higher efficiencies than combustion engines, converting a larger proportion of the fuel's energy into usable electricity.
- **Low Emissions:** The primary byproducts of hydrogen fuel cells are water and heat, contributing to cleaner energy production.
- **Versatile Applications:** Green fuel cells can be used in various sectors, including transportation (fuel cell vehicles), stationary power generation, and portable power systems.

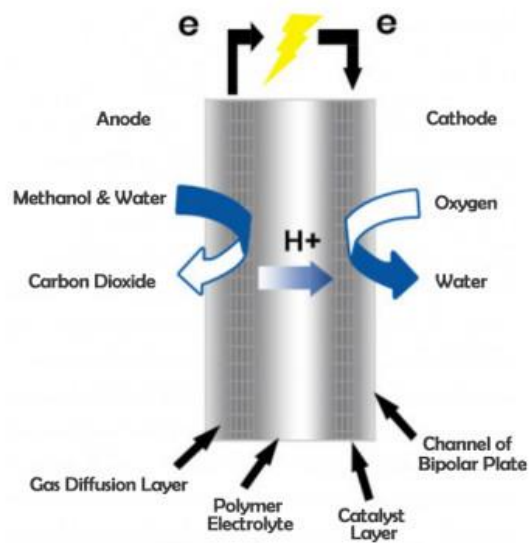
Challenges

- **Hydrogen Production:** While hydrogen is a clean fuel, its production can be energy-intensive unless derived from renewable sources, which may not be widely available or cost-effective.
- **Infrastructure:** Limited infrastructure for hydrogen distribution and fueling can hinder the widespread adoption of hydrogen fuel cells.
- **Cost:** The production of fuel cell systems and the materials used (like platinum catalysts) can be expensive, although costs are decreasing with advancements in technology.
- **Durability:** Some fuel cell types may face issues with longevity and performance stability under varying operational conditions.

2.4.1.Methanol-oxygen fuel cells

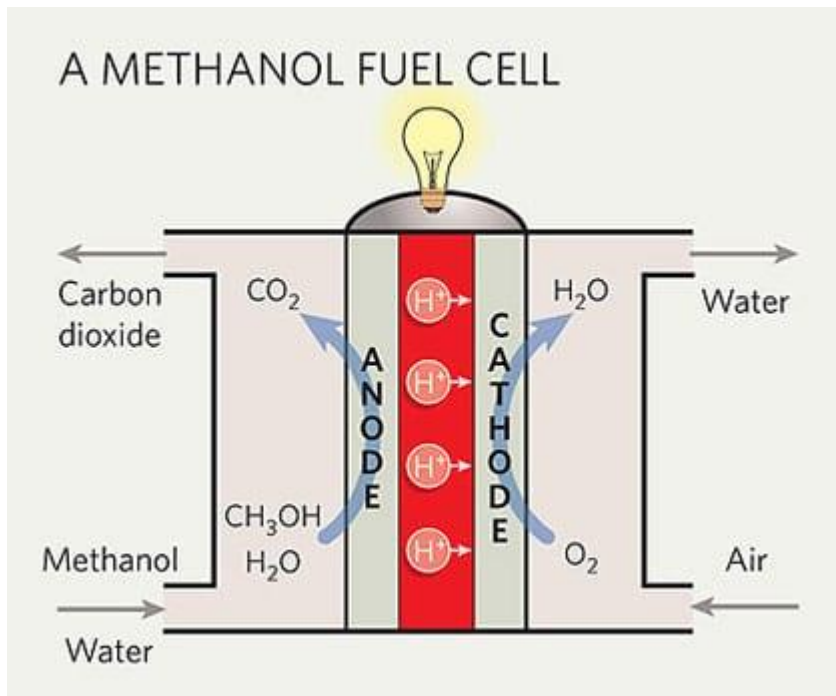
A methanol-oxygen fuel cell, also known as a direct methanol fuel cell (DMFC), is a type of fuel cell that converts the chemical energy of methanol and oxygen directly into electricity

through electrochemical reactions. Here's a detailed overview of its components, working mechanism, advantages, and challenges:



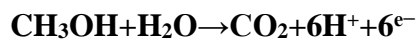
Components

1. **Anode:** The negative electrode where methanol is oxidized. Typically made of a carbon-based catalyst, often with platinum or another catalyst to enhance reaction rates.
2. **Cathode:** The positive electrode where oxygen (usually from air) is reduced. Similar to the anode, it employs catalysts for efficiency.
3. **Electrolyte:** A proton exchange membrane (PEM) that allows protons to pass through while preventing the flow of electrons, thus forcing them to travel through an external circuit.
4. **Methanol Fuel Source:** A reservoir containing liquid methanol, which is fed to the anode.



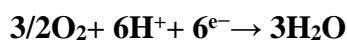
How It Works

1. **Anode Reaction:** At the anode, methanol reacts with water (from the electrolyte) to produce carbon dioxide, protons, and electrons:



Proton Movement: The produced protons move through the electrolyte membrane to the cathode.

2. **Cathode Reaction:** At the cathode, oxygen from the air combines with the protons and electrons arriving from the external circuit to form water:



3. **Electricity Generation:** The flow of electrons from the anode to the cathode through the external circuit generates electric current.

Advantages

- **Direct Use of Liquid Fuel:** DMFCs use liquid methanol, making them easier to handle and store compared to hydrogen, which requires high-pressure tanks or cryogenic storage.
- **High Energy Density:** Methanol has a higher energy density compared to hydrogen, allowing for more compact fuel storage.
- **Simpler Fueling Infrastructure:** Existing methanol distribution networks can be utilized, reducing the need for extensive new infrastructure.
- **Environmental Benefits:** The primary byproducts are water and carbon dioxide, making them relatively clean, especially when methanol is sourced from renewable biomass.

Challenges

- **Efficiency:** DMFCs generally have lower efficiencies compared to hydrogen fuel cells, partly due to methanol crossover (where methanol passes through the membrane to the cathode, leading to reduced efficiency).
- **Cost:** The use of precious metal catalysts (like platinum) can increase production costs, although research is ongoing to find cheaper alternatives.
- **Temperature Sensitivity:** DMFCs typically operate at lower temperatures (around 60-80°C), which can affect their performance under certain conditions.
- **Toxicity and Safety:** Methanol is toxic, which poses safety concerns in case of leaks or spills.

Applications

DMFCs are suitable for various applications, including:

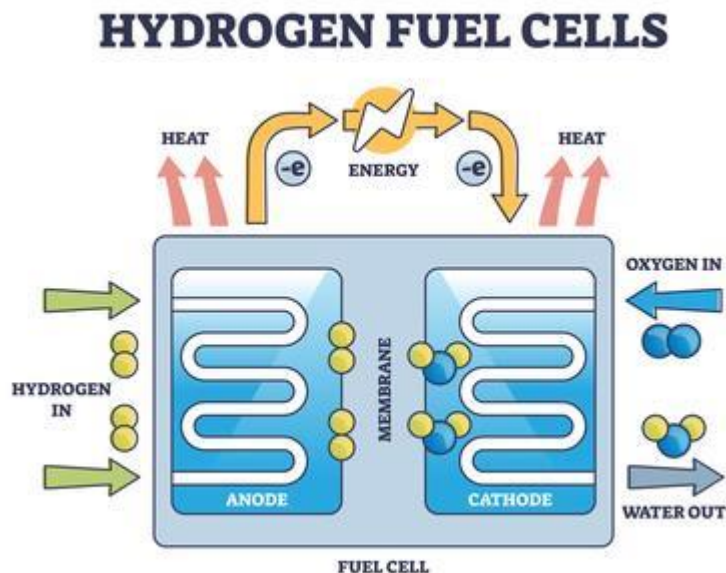
- **Portable Power:** Powering electronic devices, laptops, and mobile phones.
- **Backup Power Systems:** Providing electricity in remote locations or as backup power sources.
- **Transportation:** Potential use in vehicles, especially in hybrid systems.

Conclusion

Methanol-oxygen fuel cells offer a promising approach to clean energy generation, particularly in applications where liquid fuels are advantageous. While they face challenges related to efficiency and cost, ongoing research and development may enhance their viability and performance in the future.

2.4.2 Hydrogen fuel cells

Hydrogen fuel cells are a type of electrochemical cell that converts the chemical energy of hydrogen directly into electricity, water, and heat through a clean and efficient process. Here's a detailed overview of their components, operating principles, advantages, challenges, and applications.



Components

1. **Anode:** The negative electrode where hydrogen gas (H_2) is fed. It typically consists of a catalyst (often platinum) that facilitates the oxidation reaction.
2. **Cathode:** The positive electrode where oxygen (from air) is reduced. Like the anode, it also contains a catalyst.
3. **Electrolyte:** A proton exchange membrane (PEM) or solid oxide that allows protons (H^+ ions) to pass through while blocking electrons. This forces electrons to flow through an external circuit, generating electricity.

4. **External Circuit:** Connects the anode and cathode, allowing the flow of electrons from the anode to the cathode, creating an electric current.

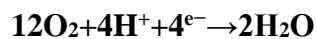
How It Works

1. **Anode Reaction:** Hydrogen gas enters the anode, where it is oxidized, releasing protons and electrons:



Proton Movement: The protons (H^+ ions) move through the electrolyte membrane to the cathode.

2. **Cathode Reaction:** At the cathode, oxygen from the air combines with the arriving protons and electrons to form water:



3. **Electricity Generation:** The flow of electrons from the anode to the cathode through the external circuit generates electrical power.

Advantages

- **High Efficiency:** Hydrogen fuel cells can achieve higher efficiencies compared to internal combustion engines and some conventional power generation methods.
- **Zero Emissions:** The primary byproduct of hydrogen fuel cells is water, making them environmentally friendly when hydrogen is sourced from renewable methods.
- **Quiet Operation:** Fuel cells operate silently, making them suitable for applications where noise reduction is important.
- **Scalability:** They can be used in a range of applications, from small portable devices to large-scale power generation.

Challenges

- **Hydrogen Production:** While hydrogen is abundant, producing it sustainably (e.g., through electrolysis using renewable energy) can be costly and energy-intensive.

- **Storage and Transportation:** Hydrogen has a low energy density by volume and requires high-pressure tanks or cryogenic storage, posing logistical challenges.
- **Infrastructure:** Limited existing infrastructure for hydrogen fueling stations can hinder widespread adoption in transportation.
- **Cost:** The use of precious metal catalysts (like platinum) increases production costs, though research is ongoing to find more cost-effective materials.

Applications

- **Transportation:** Hydrogen fuel cell vehicles (FCVs) are being developed for use in cars, buses, and trucks, offering a zero-emission alternative to gasoline and diesel vehicles.
- **Stationary Power Generation:** Fuel cells can be used for backup power, off-grid applications, and large-scale power generation.
- **Portable Power:** Hydrogen fuel cells can power portable devices, making them useful in remote locations or for emergency power.

Conclusion

Hydrogen fuel cells present a promising technology for clean energy generation and have the potential to play a significant role in the transition to a sustainable energy future. While they face challenges, particularly in hydrogen production and infrastructure, ongoing advancements in technology and policy support are likely to enhance their viability and adoption across various sectors.