THE ELECTROLYSIS PROCESS

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Abstract: This article systematizes theoretical data on the physicochemical nature of the electrolysis process. The role of electrolysis on an industrial scale in the fields of metallurgy, chemical synthesis, and energy is analyzed. Furthermore, the article highlights the significance of electrolysis in modern "green" hydrogen production technologies and innovative approaches aimed at increasing process efficiency.

Keywords: Electrolysis, electrolyte, Faraday's laws, anode, cathode, hydrogen energy, electrochemical synthesis, renewable energy, oxidation-reduction.

Among electrochemical processes, electrolysis stands out due to its versatility. **Electrolysis** is a redox (oxidation-reduction) process that occurs when a direct current passes through an electrolyte solution or melt under the influence of an external electrical power source. Today, as the global community transitions toward environmentally friendly energy sources, the technology of producing **hydrogen through water electrolysis** is gaining strategic importance.

Theoretical Foundations of Electrolysis

The process of electrolysis is based on **heterogeneous reactions** occurring at the electrodes:

1. **Reduction at the Cathode:** Positively charged ions (**cations**) migrate toward the cathode, where they gain electrons and are converted into neutral atoms or molecules.
2. **Oxidation at the Anode:** Negatively charged ions (**anions**) migrate toward the anode, where they lose electrons and undergo oxidation.

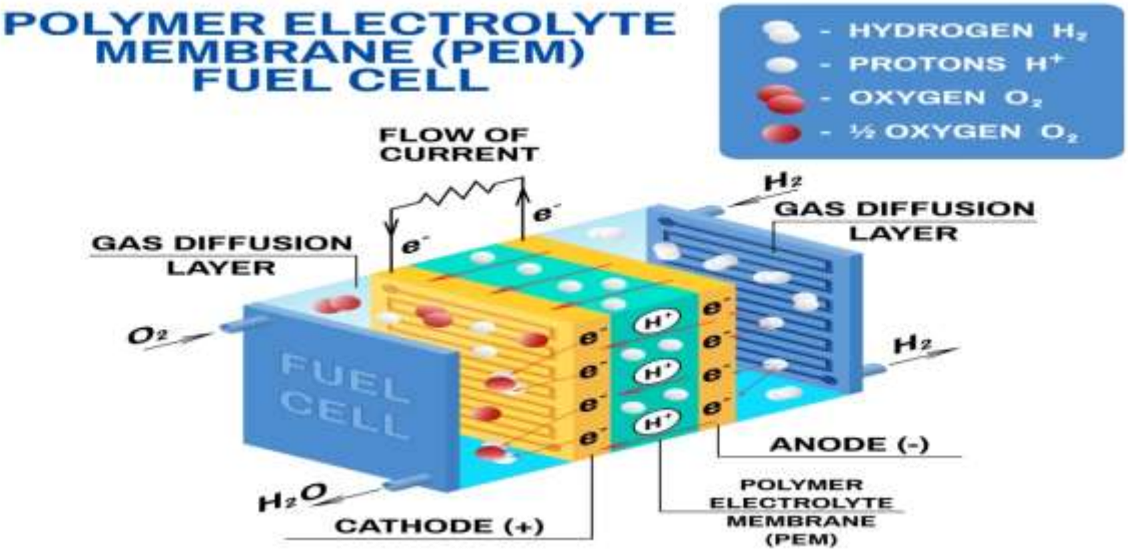
3. Modern Fields of Application

3.1. Metallurgy and Coatings

Electrolysis is utilized to extract active metals such as **aluminum, magnesium, and sodium**. Furthermore, in the field of electroplating, it is widely used to coat the surfaces of metal objects with gold, silver, or chromium (**electro-galvanizing**) for decorative purposes or corrosion protection.

3.2. Water Electrolysis and "Green" Hydrogen

Currently, the most promising direction of electrolysis is the production of pure hydrogen through **water splitting**. Utilizing solar and wind energy in this process allows for energy storage without environmental impact. Modern **PEM (Proton Exchange Membrane)** electrolyzers are demonstrating high efficiency in this regard.



Challenges in Increasing Process Efficiency

The primary challenges in the electrolysis process involve **reducing energy consumption** and preventing **electrode corrosion**. Implementing new types of catalysts—specifically utilizing affordable nanomaterials instead of platinum-group metals—and advanced ion-exchange membranes serves to lower production costs.

The Nature of Electrolysis

Electrolysis is defined as the redox (oxidation-reduction) process that occurs when an electric current is passed through an electrolyte solution or a molten electrolyte. The essence of electrolysis lies in **oxidation at the anode** and **reduction at the cathode**.

In electrolyte solutions or melts, ions carry different charges and move randomly. However, when an external electric field is applied, these ions begin to move in an organized manner toward the oppositely charged electrodes.

. For example, if graphite electrodes are immersed in a NaCl solution and connected to a DC power source, Na^+ ions move toward the **cathode** (not anode), and Cl^- ions move toward the **anode** (not cathode). As a result, sodium ions gain electrons and are reduced: $Na^+ + e^- \rightarrow Na$, while chloride ions lose electrons and are oxidized: $2Cl^- - 2e^- \rightarrow Cl_2$. Thus, sodium metal is deposited at the cathode, and chlorine gas is released at the anode. Overall reaction: $2Na^+ + 2Cl^- \rightarrow 2Na + Cl_2$. This is an oxidation-reduction reaction, with oxidation occurring at the anode and reduction at the cathode.

Coal, graphite, and metals are classified as **first-class conductors**; they conduct electricity well, but their chemical composition does not change during conduction.

When electric current passes through electrolyte solutions or melts, cations gain electrons from the cathode, and anions donate electrons to the anode, ensuring continuous current flow. Electrolytes are **second-class conductors**; when current passes through them, the substances decompose and transform into other compounds. This property distinguishes them from first-class conductors.

The higher the ion concentration in the solution, the greater the current that flows through it. The amount of current also depends on the ion charge: divalent ions conduct twice as much electricity, and trivalent ions three times as much, compared to monovalent ions. Ion mobility varies—some ions move quickly, others slowly—and this affects their transport. H^+ and OH^- ions have significantly higher mobility than others; they reach the electrodes faster during electrolysis. Therefore, solutions of acids and bases electrolyze quickly and exhibit high electrical conductivity.

The course of electrolysis depends on the nature of the electrolyte and electrodes. In aqueous solutions of electrolytes, in addition to the ions of the electrolyte itself, H^+ and OH^- ions from water are also present. When the solution is connected to a power source, both electrolyte ions and water ions migrate to the electrodes. At the cathode, the electrolyte cations compete with hydrogen ions from water; at the anode, electrolyte anions compete with hydroxide ions.

It is essential to know which ions are more active (more easily discharged). The activity of cations is determined using the **electrochemical series** (voltage series), which largely corresponds to the displacement series proposed by the Russian scientist N.N. Beketov.

If a metal stands before hydrogen in the series, its cations are difficult to reduce; therefore, they are not discharged at the cathode in aqueous solution. Instead, hydrogen ions from water are reduced, forming hydrogen molecules that are released at the cathode. Cations of metals positioned before hydrogen are not reduced during electrolysis; cations of metals after aluminum in the series are easily discharged at the cathode in aqueous solutions because these metals are not strong reducing agents. Highly active metals up to aluminum are obtained by electrolysis of their molten compounds. Cations of copper, silver, and gold readily undergo electrolysis and are immediately deposited at the cathode.

Oxygen-free anions are more easily oxidized than oxygen-containing ones. If the electrolyte anion is oxygen-free (F^-, Cl^-, Br^-, I^-, S^{2-}, CN^-), it donates electrons to the anode and is released in elemental form: $Cl^- - e^- \rightarrow Cl$; $2Cl \rightarrow Cl_2$

If the anions are oxygen-containing, hydroxide ions from water donate electrons more easily: $OH^- \rightarrow OH$; $4OH^- \rightarrow 2H_2O + O_2$

As a result, oxygen gas is released at the anode.

Electrolysis of Copper Chloride Solution

The material of the anode is also important in electrolysis. Electrodes are usually made from inert materials such as carbon (graphite) or noble (passive) metals like platinum and gold. If the anode is made of an active metal (e.g., copper or nickel), the anode itself oxidizes: its atoms turn into ions and pass into the solution, then migrate to the cathode and are reduced there.

The discharge (neutralization) of ions during electrolysis is called the primary reaction. In some cases, the substances formed by discharge may react with each other or with water (secondary reactions). For example, when current is passed through a copper chloride solution, Cu^{2+} and Cl^- ions move to the respective electrodes: At the cathode: $Cu^{2+} + 2e^- \rightarrow Cu^0$ At the anode: $2Cl^- - 2e^- \rightarrow Cl_2$

For salts of metals with standard electrode potential less than –0.41 V, when current is passed through their aqueous solutions, water molecules (not metal ions) are reduced at the cathode.

There are two types of anodes: **soluble** and **insoluble**. Soluble anodes dissolve during electrolysis and are used in industry for obtaining very pure substances or for electroplating one metal onto another.

When aqueous solutions of oxygen-containing salts are electrolyzed, water molecules are oxidized at the anode, producing oxygen gas. For salts of active metals with oxygen-containing acids (e.g., Na_2SO_4), water is reduced at the cathode and oxidized at the anode, resulting in hydrogen at the cathode and oxygen at the anode.

Currently, many metals are obtained by electrolysis of their molten salts: Al, Mg, Ca, Na; non-metals such as H_2, O_2, F_2, Cl_2, as well as alkalis, are produced by the same method.

Electrochemical series (metal chemical activity decreases from left to right, while ease of reduction of their ions increases): K^+, Ca^{2+}, Na^+, Al^{3+}, Zn^{2+}, Fe^{3+}, Sn^{2+}, Pb^{2+}, Cu^{2+}, Hg^{2+}, Ag^+, Pt^{4+}, Au^+

Anion oxidation series (ease of oxidation decreases from left to right): I^-, Br^-, S^{2-}, Cl^-, OH^-, NO_3^-, SO_4^{2-}, PO_4^{3-}

(Note: The original text contains an error here – in aqueous NaCl electrolysis, sodium metal is **not** produced at the cathode; instead, hydrogen gas and NaOH are formed. Active metals like Mg, Ca, Na and non-metals Cl_2, O_2, H_2 are obtained by electrolysis, but Na metal is produced from molten NaCl, not aqueous solution.)

Water Electrolysis Procedure

Experimental procedure:

1. Assemble the apparatus as described in the manual.

- Connect the red terminal of the apparatus to the positive side of the milliammeter.
- Fill the milliammeter indicator with 500 ml of solution (or as specified).
- Connect the power supply to the 42 V AC network via the transformer; the milliammeter indicator LED lights up brightly.
- Fill the central vessel with 5% NaOH solution.
- Fill the side vessels (right and left) with the same solution, displacing air.
- Pass current through the circuit.
- Electrolytic decomposition of water occurs in the electrode vessels.
- Oxygen gas begins to evolve in one side vessel, and hydrogen gas in the other.

Reactions: At the anode: $2O^{2-} \rightarrow O_2 \uparrow$ At the cathode: $2H^+ + 2e^- \rightarrow H_2 \uparrow$

Conclusion Electrolysis is a unique process that demonstrates the organic connection between fundamental science and practical applications. The analysis shows that in the near future, electrolysis technologies will occupy a central place not only in the chemical industry but also in ensuring global energy security, particularly in achieving carbon neutrality. It is advisable to direct scientific research toward improving process kinetics and reducing the cost of electrode materials.

6. References

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