TEACHER'S GUIDE

SCIENCE KEY CONCEPTS SERIES: CHEMISTRY

ELECTROCHEMISTRY

15 minutes, Video

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FOR USE IN: Chemistry
LEVEL: Grades 9-14
EDUCATIONAL ADVISOR: Dr. O. Roger Anderson, Columbia University: Professor Natural Sciences, Teachers College; Senior Research Scientist, Lamont-Doherty Earth Observatory

EDUCATIONAL OBJECTIVES:

To help the student understand these key concepts about electrochemistry:

- electrolysis as a source of new and useful materials
- simple tests for common gases
- the chemical changes which occur during the electrolysis of melts and aqueous solutions
- relationship of laboratory electrolysis to industrial processes

BACKGROUND INFORMATION:

In this video there are three processes represented: the electrolysis of molten ionic compounds; the electrolysis of a solution composed of an ionic compound dissolved in water; and the electroplating of metals. In all three processes, electrodes are used, often carbon electrodes because these electrodes do not react with the substances involved in the electrolysis or electroplating. However, in electroplating, a metal may be used as an electrode so that it will become plated with either the same metal or another metal. Also, the attraction of oppositely charged species is evident in the movement of negative ions toward a positive electrode and of positive ions toward a negative electrode.

When ionic compounds such as molten lead (II) bromide or zinc chloride are electrolyzed, a metal, lead or zinc, and a nonmetal, bromine or chlorine, respectively, are produced at the electrodes. The evidence of a metal is the appearance of solid bead, grey in color. Bromine and chlorine are generated as gases, each with a distinctive color.

Unlike molten ionic compounds, composed of positive metal ions and negative nonmetal ions, solutions composed of ionic compounds do not produce the metal and nonmetal, exclusively. In the case of sodium chloride solution, NaCl (aq), chlorine and hydrogen gas are generated, and hydroxide ions are generated that combine with sodium ions in solution and form sodium hydroxide. Though the sodium hydroxide is soluble - it dissolves in solution - evaporation of the water from the solution will produce solid sodium hydroxide.

The use of indicators, litmus paper and universal indicator (a mixture of a number of indicators) can be used at an electrode to indicate the generation of a substance that has acidic or alkaline properties. Litmus is a natural indicator from plants and blue litmus turns red in acid. Red litmus turns blue in base. An acid has a pH value below 7 and a base, an alkaline substance, has a pH above 7.

Electroplating involves the use of a solution containing the metal to be plated, such as copper (II) sulfate pentahydrate, $CuSO_4 \cdot 5H_2O$. Metal ions gain electrons and form solid metal that plates onto an electrode. The electrode may be the metal, itself, or perhaps another cheaper metal that a film of the metal would look good on, such as a piece of jewelry.

CONTENT OF THE VIDEO:

The video contains the following key concepts. To play only concepts 2 or 3, fast forward until you see its title. **running time min:sec**

Concept	running time min:sec
1. Electrolysis of Molten Lead Bromide and Zinc Chloride	**4:40**
2. Electrolysis of Sodium Chloride Solution	**4:50**
3. Electroplating with Copper	**5:00**

The concepts are illustrated with imaginative demonstrations, which are too dangerous, costly, or complicated to be done in the classroom. Computer animation, graphics, positioned captions, and live photography clarify and provide context for the concepts.

Electrolysis of Molten Lead Bromide and Zinc Chloride

The usefulness of electrolysis

Aluminum is manufactured by using electricity to decompose aluminum oxide.

Electrolysis of molten lead bromide

Molten lead bromide is electrolyzed using simple laboratory apparatus. This produces lead at the negative electrode and bromine at the positive electrode.

Explaining the electrolysis of molten lead bromide

Lead bromide contains positive lead ions and negative bromine ions. During electrolysis, the positive ions move to the negative electrode and the negative ions move to the positive electrode. The discharge of these ions at the electrodes is illustrated by computer animation.

Electrolysis of zinc chloride

The behavior of molten zinc chloride during electrolysis is demonstrated.

Industrial electrolysis

On a much bigger scale, a similar method is used to extract a reactive metal, such as aluminum, from its ore.

Electrolysis of Sodium Chloride Solution

Electrolyzing sodium chloride solution

The electrolysis of an aqueous solution of salt produces useful substances. This is demonstrated in the laboratory using carbon electrodes. The gas, which collects at the anode, bleaches litmus paper, which shows that the gas is chlorine. The gas at the cathode burns with a squeaky pop: it is hydrogen.

Explaining the electrolysis of sodium chloride solution

The electrolyte contains sodium and chloride ions from salt. Hydrogen and hydroxide ions come from water. Both sodium and hydrogen ions - which are positive - go to the negative electrode, but only the hydrogen ions are discharged. At the positive electrode, only the chloride ions lose their charge.

Using the products of sodium chloride electrolysis

Examples are given of how we use chlorine, hydrogen and sodium hydroxide.

Electroplating with Copper

Electrolyzing copper sulfate solution with carbon electrodes

Copper sulfate solution produces oxygen gas at the positive electrode and copper metal at the negative electrode when it electrolyzed using carbon electrodes.

Electrolyzing copper sulfate solution with copper electrodes

If copper electrodes are used, copper is again produced at the negative electrode but no oxygen is produced at the positive electrode. Mass measurements before and after electrolysis show a gain at the negative electrode and a loss at the positive electrode. This suggests that copper ions are discharged at the negative electrode but are going into solution at the other electrode.

Electroplating copper

A circuit with a reactive copper anode can be used to plate objects with copper. The object to be plated is made the negative electrode; the positive electrode is copper; and the electrolyte contains copper sulfate. The thickness of the copper deposit depends on the current flowing in the circuit.

AFTER SHOWING THE VIDEO:

In the processes illustrated in the video, reduction and oxidation occur. Reduction involves a gain of electrons and occurs at the electrode called the cathode. Oxidation involves a loss of electrons and occurs at the anode. Whether the process is the electrolysis of a molten ionic compound or a solution, or electroplating, the loss and gain of electrons must equal each other. Electrons are neither created nor destroyed in chemical reactions so the processes of oxidation and reduction occur simultaneously.

The loss and gain of electrons is illustrated below for the processes.

Electrolysis of molten lead (II) bromide, $PbBr_2$

$$Pb^{2+}(aq) + 2e^- \rightarrow Pb^o(s)$$
$$2Br^-(aq) \rightarrow Br_2^o(l) + 2e^-$$

Overall cell reaction: $Pb^{2+}(aq) + 2Br^-(aq) \rightarrow Pb^o(s) + Br_2^o(l)$

Note the "o" on the lead and bromine products. This is the oxidation number of each substance in the elemental state, which is the state of that substance at 25°C.

Electrolysis of molten zinc chloride, $ZnCl_2$

$$Zn^{2+}(aq) + 2e^- \rightarrow Zn^o(s)$$
$$2Cl^-(aq) \rightarrow Cl_2^o(g) + 2e^-$$

Overall cell reaction: $Zn^{2+}(aq) + 2Cl^-(aq) \rightarrow Zn^o(s) + Cl_2^o(g)$

In addition, the chlorine that is produced bleaches the litmus paper.

Electrolysis of sodium chloride solution, NaCl(aq)

$$2Cl^-(aq) \rightarrow Cl_2^o(g) + 2e^-$$
$$2H_2O(l) + 2e^- \rightarrow 2OH^-(aq) + H_2(g)$$

Overall cell reaction: $2H_2O(l) + 2Cl^-(aq) \rightarrow 2OH^-(aq) + H_2(g) + Cl_2(g)$

The OH^- ions combine with Na^+ ions in solution and produce NaOH(aq).

Electroplating of copper, Cu(s)

When two copper electrodes are used:

$$Cu^o(s) \rightarrow Cu^{2+}(aq) + 2e^-$$
$$Cu^{2+}(aq) + 2e^- \rightarrow Cu^o(s)$$

Overall cell reaction: $Cu(s) \rightarrow Cu(s)$

Illustrated in this process is conservation of mass as shown by an equal loss in mass of one electrode and an equal gain in mass by the other electrode.

There were several questions addressed in the video that were not answered.

1. Why doesn't a compound conduct when it is a solid?

Solid ionic compounds do not conduct a current. The oppositely charged ions attract each other and form a crystalline lattice structure where there are no free ions. Solid ionic compounds are poor electrical and thermal conductors, but when molten, the ions are freely mobile and therefore they become excellent conductors.

2. What gas combines with water to form an acidic solution? What is responsible for the bleaching action?

When chlorine gas is generated, it combines with water and forms hypochlorous acid, HOCl, which tests acidic and also bleaches the litmus paper.

3. What evidence is there that a chemical reaction takes place?

Various factors are indicative of a chemical reaction such as: generation of a gas, a change in temperature, a color change, an indicator changing color, the formation of a solid.

4. What happens to the color of a solution as copper (II) ions, Cu^{2+}, are removed from a solution?

Copper (II) ions in solution are a distinct blue color. When copper (II) ions are involved in a reduction oxidation reaction and the copper ions gain electrons, copper metal is formed. The removal of the ions from the solution results in the disappearance of the blue color.

EXPLORING AND INVESTIGATING:

1. What plant does the indicator, litmus, come from? What is the structure of the litmus indicator? Why does the indicator change color in acidic and basic solutions?
2. There are many natural indicators. Test red cabbage juice or black bean juice with household products such as lemon juice, baking soda, toothpaste, ammonia, liquid detergent, window cleaner, and orange juice.
3. If bromine and chlorine gases have color, do fluorine and iodine gases have color? If so, what is the color of their gases? What is the name of the family in the Periodic Table to which these elements belong?
4. Write the reduction and oxidation reactions for molten magnesium iodide.
5. If you wear a copper ring and your skin around the ring becomes a greenish color, what reaction is taking place?

Caution: observe all safety regulations of your school when doing experiments in the laboratory. Check with the appropriate officer in your school before doing these experiments.

Further Information on the Internet

Charles Hall: A historical account of the development by Charles M Hall of a method for the electrolytic extraction of aluminum. (Level: student) http://chemserver.chem.oberlin.edu/CharlesMartinHall.html

Copper: Information produced by the Copper Development Association of North America, which contains teaching resources about the refining of copper and the commercial production of copper and its alloys. (Level: student and teacher) http://www.copper.org/general/homepage.htm

Electrolytic processes: Provides an overview of the application of electrolytic processes in the production and refining of metals. (Level: teacher) http://www.chem.ualberta.ca/courses/plambeck/p102/p02113.htm

Galvanizing: The home page of the metal finishing industry. Includes FAQs, which provide support materials for teaching about galvanizing and other electrochemical processes used in the production of metals. (Level: student and teacher) http://www.finishing.com/Home/about.html

Tin plate: some descriptive information about the commercial importance of tin and the processes involved in tin plate production. (Level: student) http://me.mit.edu/2.01/Taxonomy/html/Materials.html

Guide written by: Dr. Julie Ealy and James Ealy, Teachers College, Columbia University

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BENCHMARK MEDIA 569 NORTH STATE ROAD, BRIARCLIFF MANOR, NY 10510
TEL: 914/762-3838, 1/800-438-5564 FAX: 914/762-3895 E-MAIL: benchmedia@aol.com