Lesson Plan: Exploration of Electrolytic Cells

FOR THE TEACHER

Summary
In this lesson, students will build several electrolytic cells, discuss and diagram their cells to further their understanding of electrolysis, and use qualitative and quantitative analysis of the electrolysis of potassium iodide. Finally, students will practice and be assessed on their knowledge of electrolysis on AP exam-level questioning.

Grade Level
High School (AP Chemistry)

NGSS Alignment
This lesson will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS3-1**: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- **Scientific and Engineering Practices**:
  - Using Mathematics and Computational Thinking
  - Analyzing and Interpreting Data

AP Chemistry Curriculum Framework
This lab activity supports the following units, topics, and learning objectives:

- **Unit 9: Applications of Thermodynamics**
  - **Topic 9.7**: Galvanic (Voltaic) and Electrolytic Cells
    - ENE-6.A: Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.
  - **Topic 9.10**: Electrolysis and Faraday’s Law
    - ENE-6.D: Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.

Objectives
By the end of this lesson, students should be able to

- Build a working electrolytic cell, identifying components and the flow of electrons.
- Identify components of an electrolytic cell from a reduction/oxidation reaction.
- Use stoichiometry to predict/calculate products of an electrolytic reaction.
- Use Gibbs’ Free Energy and the relationship of Q vs. K to determine the favorability of an electrolytic reaction.

Chemistry Topics
This lesson supports students’ understanding of

- Electrochemistry
- Electrolytic Cells
- Galvanic Cells
- Electrolysis of metals and solutions
- Gibb’s Free Energy
Time
**Teacher Preparation:** 20-30 minutes
**Lesson:** 90-120 minutes
- **Suggested Day 1:**
  - 25-30 minutes for electroplating activity and drawing of cell
  - 15-20 minutes electrochemistry practice
- **Suggested Day 2:**
  - 30-45 minutes for solution electrolysis lab activity
- **Suggested Day 3:**
  - 15-20 minutes for assessment

Materials
- **Electroplating activity (per group)**
  - 1 DC power supply, 10V
  - 2 Electrode cables/alligator clips (red/black for +/–)
  - 2-3 Medium-sized beakers (150-250mL)
  - 1.0M acetic acid solution (50-100mL)
  - 1.0M zinc nitrate solution (100-150mL), enough to cover the copper
  - 1 Zinc metal strip, approximately 4-5” in length
  - Copper metal strips (sizes determined by students), likely 3-4” square
  - Permanent markers
  - Acetone (~50mL)

- **Solution electrolysis lab (per group)**
  - 1 Glass “U-tube” (can be made with glass tubing/bunsen burner)
  - 1 Ring stand
  - 1 DC power supply, 10V
  - 2 Electrode cables/alligator clips (red/black for +/–)
  - 1 Ring stand clamp
  - 1.0M KI solution (50-100mL)
  - Phenolphthalein (5-10 drops)
  - 2 graphite electrodes (pencil lead works fine!)
  - 2-3 Disposable pipettes
Safety

- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
- When working with acids, if any solution gets on students’ skin, they should immediately alert you and thoroughly flush their skin with water.
- When diluting acids, always add acid to water.
- Inspect wiring of equipment before each use.
- Replace all frayed or damaged electrical cords immediately.
- Only equipment with three prongs (ground) should be used in the laboratory.
- Minimize the potential for water or chemical spills on or near electrical equipment.
- Ensure that GFCI outlets are installed and used when water is present within 6 feet.
- The reaction involved in the electrolysis of potassium iodine may produce halogen gas/ions. Waste solutions should be reduced with sodium thiosulfate before disposal, and students should be instructed to not “whiff” their solutions.

Teacher Notes

- Depending on the length of class periods, this lesson is best broken up into 3 days/class periods of 45-50 minutes each. If on block schedule, this could be completed in 2 blocks.

Lesson Outline:

- **Day 1:** The first day is intended as a review of electrochemical systems and electrolysis, with the students building a simple electrochemical cell, followed by some electrochemistry practice to aid students in their knowledge of electrochemistry stoichiometry, balancing reduction/oxidation reactions, etc. The electroplating activity is a fun, simple way for students to see electroplating in action, using copper and zinc electrodes, which students should be familiar with in their study of Galvanic cells, but then by using a power source, students will plate the copper with zinc.
- Through the use of a permanent ink marker (e.g. Sharpie), students can write messages (this lesson commonly occurs around Valentine’s Day in my class, so students often write “electroplated valentine messages”) which will then be protected from the electroplating process and then can be washed off with acetone, exposing the copper underneath. Depending on the availability of copper, students can do this as a group, or independently. Alternatively, students can cover up the parts of the copper around their message with marker, leaving only the message to be plated. Note that the electroplating works best with freshly cleaned copper, which can be achieved by dipping it in 1.0M acetic acid or hydrochloric acid prior to the electroplating process. Examples are shown below:
After the electroplating process, students can polish their “messages” and (optional) take-home an example of their classwork. This activity doesn’t take very long, only about 25-30 minutes, and students can draw a diagram of their electrolytic cell while waiting their turn for electroplating.

When the activity is complete, students should clean up their lab stations, ensuring the power supplies are turned off and disconnected, and then begin the review electrochemistry questions. These will help students explore the differences between galvanic and electrolytic cells, as well as diagram cells, and identify the parts of an electrochemical cell.

Day 2: The second day is a more thorough exploration of electrolysis of solutions, using the electrolysis of potassium iodide to produce elemental iodine and explore the chemistry involved at both electrodes. This setup is a bit more involved, and will likely take a full class period.

*As an optional activity, students can create their own glass U-tubes, by learning how to shape, bend, and anneal glass tubing. More info can be found in this Flinn video.*

Using the U-tube setup, in groups of 2-3, students will:
  o Fill the tube with potassium iodide solution.
  o Add 5-10 drops of phenolphthalein to their solution.
  o Then using graphite electrodes (pencil “lead” works great for this), students will run their electrolysis for 10-15 minutes, until the products of the electrolysis are visible (most evident will be the yellowish-brown iodine formed from the oxidation at the anode, and the pink color of phenolphthalein at the cathode, indicating the presence of hydroxide ions in the solution from the reduction of water).
  o Students will then record their observations and use these to inform their conclusions on the student handout.

Images from this lab, from the Royal Society of Chemistry can serve as a helpful set-up reference.

Day 3: An excellent assessment of student understanding of electrolysis comes from the 2013 Exam, Free Response Question 2 from AP Central. Use question 2 as an assessment/culminating activity. It could be included with day 2 if time allows, otherwise can be used as a great formative assessment after this lesson to measure students’ understanding of the electrolytic process.

Answers for the Assessment question is below for reference:
  o Part (a):

\[
\frac{235 \text{ g Al} \times \frac{1 \text{ mol Al}}{26.98 \text{ g Al}}}{3 \text{ mol e}^-} = 8.71 \text{ mol Al}
\]

\[
\text{Al}^{3+} + 3 \text{ e}^- \rightarrow \text{Al}
\]

\[
8.71 \text{ mol Al} \times \frac{3 \text{ mol e}^-}{1 \text{ mol Al}} = 26.1 \text{ mol e}^-
\]

  o Part (b):

\[
26.1 \text{ mol e}^- \times \frac{9.65 \times 10^4 \text{ C}}{1 \text{ mol e}^-} = 2.52 \times 10^6 \text{ C}
\]

\[
\frac{2.52 \times 10^6 \text{ C}}{152 \text{ C/s}} = 1.66 \times 10^4 \text{ s}
\]

  o Part (c):
\[ \text{mol CO}_2 = 8.71 \text{ mol Al} \times \frac{3 \text{ mol CO}_2}{4 \text{ mol Al}} = 6.53 \text{ mol CO}_2 \]

\[ PV = nRT \]

\[ V = \frac{nRT}{P} = \frac{(6.53 \text{ mol})(0.0821 \frac{L \cdot \text{atm}}{\text{mol} \cdot K})(301K)}{0.952 \text{ atm}} = 1.70 \times 10^2 \text{ L CO}_2 \]

- Part (d): Various; ionic compounds only conduct electricity when molten or aqueous, therefore aluminum oxide must be liquid in order for ions to be mobile.

- Part (e)(i):

\[ E^\circ = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = -0.83 \text{ V} - (-2.35 \text{ V}) = 1.52 \text{ V} \]