Petri Dish Electrolysis

Electrolysis Reactions

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Introduction

Electrolysis is defined as the decomposition of a substance by means of an electric current. When an electric current is passed through an aqueous solution containing an electrolyte, the water molecules decompose via an oxidation–reduction reaction. Oxygen gas is generated at the anode, hydrogen gas at the cathode. Depending on the nature of the electrolyte, different reactions may take place at the anode and the cathode during the electrolysis of aqueous solutions. Build simple and inexpensive electrochemical cells using Petri dishes to compare the reactions of sodium sulfate, potassium iodide, and tin(II) chloride.

Concepts

- Electrolysis
- Anode and cathode
- Oxidation and reduction
- Acid–base indicators

Materials

Phenolphthalein indicator solution, 0.5%, 1 mL
Potassium iodide solution, KI, 0.5 M, 20 mL
Sodium sulfate solution, Na_2SO_4, 0.5 M, 20 mL
Starch solution, 0.5%, 1 mL
Tin(II) chloride solution, acidified, $SnCl_2$, 1 M, 20 mL*
Universal indicator solution, 5 mL
9-V Battery
Battery cap w/ alligator clip leads
Beral-type pipets, 2
Paper clips, 2
Paper towels
Pencil leads, 7 mm, 2
Petri dish
Stirring rod
Wash bottle and distilled water

**See the* Preparation *section.*

Safety Precautions

The acidic tin(II) chloride solution is corrosive to body tissue and moderately toxic by ingestion. Phenolphthalein and universal indicators solutions contain ethyl alcohol and are flammable liquids. Keep away from flames and heat. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

Prepare acidified 1 M tin(II) chloride solution by dissolving 22.5 g of tin(II) chloride dihydrate ($SnCl_2{\cdot}2H_2O$) in 100 mL of 1 M hydrochloric acid.

Procedure

1. Place a clean Petri dish on the overhead projector stage and carefully pour about 20 mL of 0.5 M sodium sulfate solution into the dish.
2. Add 2–3 mL of universal indicator solution and stir to mix. The solution should be a rich, transparent green color (neutral pH, 7).
3. Break a pencil lead in half. Attach the two pencil leads to opposite sides of the Petri dish with the alligator clips on the battery cap. Connect the battery cap to the 9-V battery (see Figure 1).

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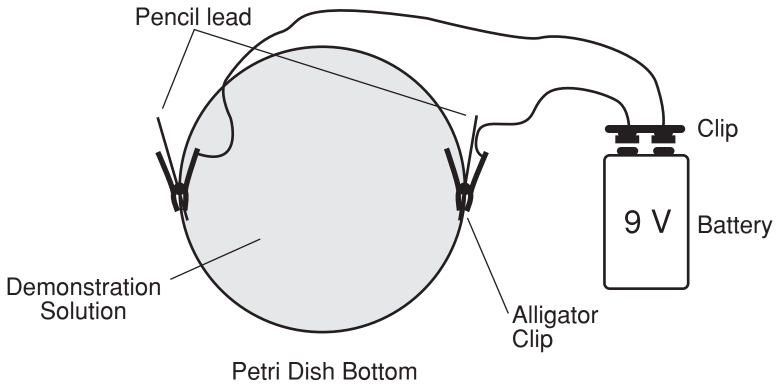

Figure 1. Demonstration Setup.

4. Make sure each pencil lead is submerged in the sodium sulfate solution. Try to keep the alligator clips out of the liquid if possible.
5. Let the demonstration run for 3–5 minutes. Observe and record all changes as the current flows through the electrolysis solution. Be specific—compare the changes at the pencil leads attached to the positive (+) and negative (–) terminals of the battery. *Note:* The conducting surfaces at which electric current passes into and out of the solution are called electrodes. The electrode at which oxidation occurs is called the anode, while the electrode at which reduction occurs is called the cathode. In an electrolytic cell, the anode is (+) and the cathode is (–). The general convention is to show the anode on the left and the cathode on the right in figures of an electrochemical cell. Following this convention when performing this demonstration will help avoid confusion.
6. Note the changing colors over time. A purple color will appear the cathode and an orange color will appear at the anode. Soon the entire spectrum of universal indicator color changes may be visible. What pH changes are responsible for the various colors?
7. Observe the formation and appearance of gas bubbles at each electrode. Can you identify which gas is hydrogen and which is oxygen based on the rate of bubbling and the apparent solubility of the gases in the solution?
8. Disconnect the alligator clips from the Petri dish and carefully remove the carbon pencil leads from the solution. Rinse the pencil leads with distilled water from a wash bottle and gently pat dry with a paper towel.
9. Stir the sodium sulfate solution in the Petri dish and observe the final indicator color of the solution after mixing. It should be green, corresponding to no net production of H^+ or OH^- ions in the electrolysis of water.
10. Pour the solution from the Petri dish into a waste beaker and rinse well with distilled water.
11. Place the clean Petri dish on the overhead projector stage and carefully add about 20 mL of 0.5 *M* potassium iodide solution.
12. Add 3–5 drops of phenolphthalein solution to the potassium iodide solution and stir to mix.
13. Attach clean pencil lead electrodes to each alligator clip lead on the battery cap and submerge the electrodes into the KI solution.
14. Let the demonstration run for 2–3 minutes. Observe and record all changes as the current flows through the electrolysis solution. Be specific—compare the changes at the anode and the cathode. A yellow-brown suspension will form at the anode. The solution around the cathode will turn dark pink and there will be rapid gas bubbling at the cathode. Discuss the pH change responsible for the color change of the phenolphthalein indicator and the possible identity of the yellow-brown product. Compare and contrast the reactions occurring at each electrode in the electrolysis of water (sodium sulfate) and potassium iodide.
15. Remove the pencil lead electrodes from the electrolysis solution and disconnect them from the battery cap. Carefully rinse the pencil leads with distilled water from a wash bottle and gently pat dry on a paper towel.
16. Add two drops of starch solution to the potassium iodide solution in the Petri dish and record observations in the data table. The solution around the anode will turn dark blue or black (positive test for iodine).

17. Pour the solution from the Petri dish into a waste beaker and rinse well with distilled water.
18. Place the clean Petri dish on the overhead projector stage and add about 20 mL of 1 *M* tin(II) chloride solution.
19. Connect one ***paper clip*** to each alligator clip lead on the battery cap and attach the paper clips to opposite sides of the Petri dish.
20. Attach the battery cap with alligator clip leads to the 9-V battery and observe the changes at the anode and the cathode as electrolysis proceeds. A milky-white cloudiness appears at the anode due to tin(IV) chloride and beautiful metallic tin(0) crystals form at the cathode.
21. Allow the reaction to continue for 1–2 minutes and observe the pattern of crystal growth. Tin crystals grow in a feather-like (fractal) pattern, producing a beautiful "crystal tree."
22. Gently remove the alligator clip leads from the paper clips and carefully switch the polarity of the electrodes. Attach the alligator clip from the negative battery post to the previous anode (left-hand side above) and the alligator clip from the positive battery post the previous cathode (the right-hand side above.)
23. Observe the changes at the new anode and the new cathode. The reactions are reversed—new tin crystals grow from the previous anode and the tin crystals at the previous cathode dissolve into solution.
24. Disconnect the battery cap from the battery to stop the reaction.
25. Carefully decant the solution from the Petri dish into a clean waste beaker (avoid pouring the tin crystals). The tin crystals may be poured onto several layers of paper towels.
26. The electrolysis products may include dilute halogen solutions (chlorine, bromine, and iodine). *Working in the hood*, carefully pour the contents of the Petri dish into a waste beaker containing sodium thiosulfate solution. Sodium thiosulfate will reduce the halogen waste products. Allow the beaker to stand in the hood overnight.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Electrolysis of potassium iodide generates iodine. The waste solution may reduced with sodium thiosulfate according to Flinn Suggested Disposal Method #12a. The acidic tin chloride waste solution may be neutralized with base according to Flinn Suggested Disposal Method #24b.

Tips

- Electrolysis of sodium chloride generates chlorine gas at the anode. Based on their standard reduction potentials, oxidation of chloride ion to chlorine (E_o = –1.36 v) should be less favorable than oxidation of water to oxygen (E_o = –1.23 V). However, there is a significant overvoltage for oxidation of water, and oxidation of chloride competes with oxidation of water under typical electrolysis conditions. Although the cause of the overvoltage is poorly understood, it is generally believed to be due to a kinetically slow reaction at the anode.
- Potassium iodide solution is light- and air-sensitive. Prepare the solution fresh within two week of its anticipated use and store the solution in a dark bottle.
- Electrolysis of salt solutions takes place at concentrations greater than about 0.2 M. We recommend using 0.5 *M* solutions for potassium iodide and sodium sulfate—electrolysis is very rapid and the color changes are more obvious than in 0.2 *M* solutions.
- A black coating forms on the paper clip electrodes when the paper clips are placed in the tin(II) chloride solution. This is due to a spontaneous single replacement reaction between the metal in the paper clips and tin(II) ions. The black coating will not interfere with the electrolysis reaction.
- Electrolysis is a challenging topic for students. The demonstration provides a great critical-thinking (inductive reasoning) exercise for students to identify the products of the separate half-reactions based on the observations at each electrode. Write down all of the possible oxidation and reduction half-reactions for each salt solution on the board, and ask students to interpret the evidence and determine the actual products.

- Have individual student groups research and then present a class seminar on (a) the historical role of electrolysis in the discovery of potassium, sodium, magnesium, calcium, strontium, and barium; and (b) the modern importance of electrolysis in the production of industrial chemicals, including aluminum, sodium hydroxide, chlorine, etc.

Discussion

An electrolytic cell consists of a source of direct electrical current connected to two electrodes in a solution of an electrolyte or in a molten salt solution. The electrodes act as external conductors and provide surfaces at which electron transfer will take place. Electrons flow from the anode, which is the site of oxidation, to the cathode, which is the site of reduction. The battery or other voltage source serves as an electron "pump," pushing electrons into the electrode from the negative pole and pulling electrons from the electrochemical cell at the positive pole. The negative electrode, where the electrons enter the electrolysis setup, is the cathode. The electrons are "consumed" in a reduction half-reaction. Electrons are generated at the anode, the positive electrode, via an oxidation half-reaction. The migration of ions in the electrolyte solution completes the electrical circuit.

The following half-reactions occur in the electrolysis of water.

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

Reduction-half-reaction (cathode) $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

Electrolysis of an aqueous salt solution may generate products other than oxygen or hydrogen if the salt contains ions that are more easily oxidized or reduced than water molecules.

The electrolysis of aqueous potassium iodide (KI), for example, generates iodine at the anode and hydrogen gas at the cathode. The products of the reaction demonstrate that oxidation of iodide ions (I^-) to iodine (I_2) occurs more readily than oxidation of water. The overall reaction is the sum of the oxidation and reduction half-reactions.

Oxidation half-reaction (anode) $2I^-(aq) \rightarrow I_2(s) + 2e^-$

Reduction-half-reaction (cathode) $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

Overall reaction $2H_2O(l) + 2I^- \rightarrow H_2(g) + I_2(l) + 2OH^-(aq)$

The electrolysis of tin(II) chloride is an interesting example because tin(II) ions can be both oxidized and reduced. Tin(II) ions are oxidized to tin(IV) ions at the anode and are reduced to metallic tin at the cathode. Insoluble tin(IV) chloride is observed as a milky white precipitate at the anode.

Oxidation half-reaction (anode) $Sn^{2+}(aq) \rightarrow Sn^{4+}(aq) + 2e^-$

Reduction half-reaction (cathode) $Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$

Overall reaction $2Sn^{2+}(aq) \rightarrow Sn^{4+}(aq) + Sn(s)$

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12

Systems, order, and organization

Evidence, models, and explanation

Content Standards: Grades 9–12

Content Standard A: Science as Inquiry

Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter

Answers to Worksheet

Data Table

Electrolyte (Salt Solution)	Observations	
	Anode	**Cathode**
Sodium Sulfate	Solution around the electrode gradually turns yellow and then orange or red. Slow gas bubbling—large bubbles appear to dissolve in solution.	Solution around the electrode quickly turns purple and there is immediate and very rapid gas bubbling. Lots of tiny little bubbles appear to "pop."
Potassium Iodide	Yellow substance formed at positive electrode and dissolved in solution. Brownish-yellow solid observed on electrode. Solution turned black when starch was added.	Rapid gas bubbling observed at negative electrode. Solution immediately surrounding the cathode turned bright pink.
Tin(II) Chloride	Small amount of milky white precipitate or cloudiness.	Beauiful metallic silver crystals grow in a dendritic pattern, producing a "crystal tree."

Answers to Discussion Questions

1. (a) Compare the color changes observed at the positive (+) and negative (–) electrodes in the electrolysis of sodium sulfate. What ions were produced at each electrode?

The indicator color changed to red-orange at the (+) electrode. This is due to the formation of H^+ (H_3O^+) ions—universal indicator is red in acidic solutions (pH <4), when the concentration of H^+ ions is greater than the concentration of OH^- ions. The indicator color changed to purple at the negative electrode. This is due to the formation of OH^- ions—universal indicator is purple in basic solutions (pH >10), when the concentration of OH^- ions is greater than the concentration of H^+ ions.

(b) Write out the oxidation and reduction half-reactions for the decomposition of water and identify which reaction occurred at each electrode, based on the indicator color changes.

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

Reduction $H_2O(l) \rightarrow H_2(g) + OH^-(aq)$

2. Compare the rates of gas evolution at the positive (+) and negative (–) electrodes. What gas was produced at each electrode? Explain, based on the balanced chemical equation for the decomposition of water.

The rate of gas evolution was greater at the negative electrode, where hydrogen gas was formed. According to the balanced chemical equation for the decomposition of water, two moles of hydrogen gas are formed for every mole of oxygen gas that is released.

3. The following oxidation and reduction half-reactions are possible for the electrolysis of potassium iodide solution (the solution components are water molecules, potassium ions (K+), and iodide ions (I–).

$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$ $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

$K^+(aq) + e^- \rightarrow K(s)$ $2I^-(aq) \rightarrow I_2(s) + 2e^-$

(a) What product was formed at the anode in the electrolysis of potassium iodide solution? Explain based on your observations—be specific!

*The substance formed at the anode is an oxidation product. The product is yellow, water-soluble, and turns black when starch is added—**iodine**.*

(b) What product was formed at the cathode in the electrolysis of potassium iodide solution? Explain based on your observations.

*The substance formed at the cathode is a reduction product. The product is a gas, and is accompanied by the formation of a base (phenolphthalein turned pink). The product is **hydrogen**, and **hydroxide ions** are formed as a byproduct.*

(c) Write the net ionic equation for the overall redox reaction in the electrolysis of aqueous potassium iodide. Hint: Remember to balance the electrons!

$$2H_2O(l) + 2I^- \rightarrow H_2(g) + I_2(aq) + 2OH^-(aq)$$

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Petri Dish Electrolysis* activity, presented by Irene Cesa, is available in *Electrolysis Reactions*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Petri Dish Electrolysis* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Colorful Electrolysis* and *Electrolysis Reaction* Kits available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6894	Electrolysis Reactions—Student Laboratory Kit
AP6467	Colorful Electrolysis—Chemical Demonstration Kit
P0019	Phenolphthalein Indicator Solution, 1%, 100 mL
P0171	Potassium Iodide Solution,0.5 M, 500 mL
S0353	Sodium Sulfate Solution, 0.5 M, 500 mL
S0151	Starch Solution, 0.5%, 500 mL
S0354	Tin(II) Chloride Solution, 1 M, 500 mL
U0001	Universal Indicator Solution, 100 mL
AP8954	Battery Clip with Alligator Clip Leads
GP3019	Petri Dish, Borosilicate Glass, 100 × 15 mm
AP1817	Pencil Leads

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Petri Dish Electrolysis Worksheet

Data Table

Electrolyte (Salt Solution)	Observations	
	Anode	Cathode
Sodium Sulfate		
Potassium Iodide		
Tin(II) Chloride		

Discussion Questions

1. (a) Compare the color changes observed at the positive (+) and negative (–) electrodes in the electrolysis of sodium sulfate. What ions were produced at each electrode?

   (b) Write out the oxidation and reduction half-reactions for the decomposition of water and identify which reaction occurred at each electrode, based on the indicator color changes.

2. Compare the rates of gas evolution at the positive (+) and negative (–) electrodes. What gas was produced at each electrode? Explain, based on the balanced chemical equation for the decomposition of water.

3. The following oxidation and reduction half-reactions are possible for the electrolysis of potassium iodide solution (the solution components are water molecules, potassium ions (K^+), and iodide ions (I^-).

   $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$ $\quad$ $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

   $K^+(aq) + e^- \rightarrow K(s)$ $\quad$ $2I^-(aq) \rightarrow I_2(s) + 2e^-$

   (a) What product was formed at the anode in the electrolysis of potassium iodide solution? Explain based on your observations—be specific!

   (b) What product was formed at the cathode in the electrolysis of potassium iodide solution? Explain based on your observations.

   (c) Write the net ionic equation for the overall redox reaction in the electrolysis of aqueous potassium iodide. Hint: Remember to balance the electrons!