Electrolysis of Potassium Iodide

Electrolysis Reactions

Introduction

Electrolysis is defined as the decomposition of a substance by means of an electric current. When an electric current is passed through water containing an electrolyte, the water molecules decompose via an oxidation–reduction reaction. Oxygen gas is generated at the anode, hydrogen gas at the cathode. The purpose of the electrolyte, such as sodium sulfate, is to provide ions that will “carry” the current through the solution. Depending on the nature of the electrolyte, different reactions may take place at the anode and the cathode during the electrolysis of an aqueous solution.

Concepts

- Electrolysis
- Anode and cathode
- Oxidation and reduction
- Cell potential

Background

An electrolytic cell consists of a power source or a battery connected to two electrodes in a solution of an electrolyte. 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 power source or battery serves as an electron “pump,” pushing electrons into the electrolytic cell from the negative pole and pulling electrons from the cell at the positive pole. The negative electrode, where the electrons enter the cell, is the cathode. The electrons are “consumed” in a reduction half-reaction at the cathode. 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 solution may generate products other than oxygen or hydrogen if the electrolyte contains ions that are more easily oxidized or more easily reduced than water molecules. The electrolysis of aqueous silver nitrate ($AgNO_3$), for example, produces oxygen at the anode and silver metal at the cathode. The products of the reaction demonstrate that reduction of silver ions (Ag^+) to silver (Ag) occurs more readily than reduction of water. The overall reaction is the sum of the oxidation and reduction half-reactions:

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

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Experiment Overview

The purpose of this experiment is to identify the products obtained in the electrolysis of aqueous potassium iodide, copper(II) bromide, and sodium chloride solutions. The electrolysis reactions will be carried out in a electrolytic cell consisting of a Petri dish, a 9-V battery, and carbon (pencil lead) electrodes (Figure 1).

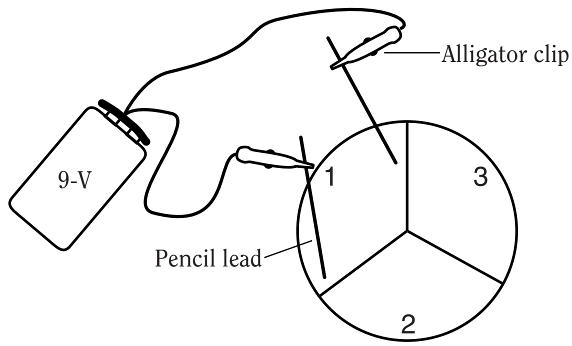

Figure 1. Petri Dish Electrolysis.

Pre-Lab Questions

1. Complete the following table summarizing the general properties of the electrodes in an electrolytic cell.

Electrode	Oxidation or Reduction	Sign of Electrode
Anode		
Cathode		

2. Sodium metal is produced commercially by the electrolysis of molten sodium chloride. The by-product of the reaction is chlorine gas. (a) Write the oxidation and reduction half-reactions for the electrolysis of molten sodium chloride. (b) Identify the substance that is oxidized and the substance that is reduced. (c) Write the balanced chemical equation for the overall reaction.
3. Sodium metal is easily oxidized—it is a very reactive metal. Sodium reacts spontaneously with water at room temperature to give sodium hydroxide and hydrogen gas. Would you expect to observe sodium metal in the electrolysis of aqueous sodium chloride? Explain.

Materials

Copper(II) bromide solution, $CuBr_2$, 0.2 *M*, 8 mL

Phenolphthalein indicator solution, 0.5%, 1 mL

Potassium iodide solution, KI, 0.5 *M*, 8 mL

Sodium chloride solution, NaCl, 0.5 *M*, 8 mL

Sodium thiosulfate "waste beaker," $Na_2S_2O_3$, 3 *M* in H_2SO_4 (for disposal)

Starch solution, 0.5%, 1 mL

Distilled water and wash bottle

Battery, 9-V

Battery cap with alligator clip leads

Beral-type pipets, 3

Paper towels

Pencil lead electrodes, 0.9-mm, 2

Petri dish, partitioned, 3-way

Stirring rod

Wax pencil or marking pen

Safety Precautions

Copper(II) bromide solution is toxic by ingestion and may be irritating to the eyes, skin, and respiratory tract. Phenolphthalein is an alcohol-based solution and is a flammable liquid. Keep away from flames and heat. The electrolysis reactions will generate small amounts of gases. Do not breathe the vapors. 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.

Procedure

1. Place the partitioned Petri dish on a sheet of white paper. Observe that the compartments or segments of the Petri dish are labeled 1, 2, and 3.
2. Carefully pour about 8 mL of 0.5 M potassium iodide solution into the first compartment of the Petri dish until the compartment is one-third to one-half full.
3. Add 3 drops of phenolphthalein solution and stir to mix.
4. Connect the battery cap to the 9-V battery. Carefully attach a "pencil lead" electrode to each alligator clip lead. *Caution:* Do not allow the electrodes to touch each other.
5. Hold the red (+) lead from the 9-V battery in one hand and the black (–) lead in the other hand. Keeping the electrodes as far apart as possible, dip the pencil lead electrodes into the potassium iodide solution.
6. Let the electric current run for 1–2 minutes while observing any changes in the potassium iodide solution. Record all observations in the data table—be sure to indicate where changes take place (at the anode or the cathode). Refer to the *Background* section and the *Pre-Lab Questions* for the properties of the electrodes.
7. Remove the pencil lead electrodes from the electrolysis solution. Carefully rinse the electrodes with distilled water from a wash bottle and gently pat dry on a paper towel.
8. Add two drops of starch solution to the potassium iodide solution after electrolysis and record observations in the data table.
9. Carefully pour about 8 mL of 0.5 M sodium chloride solution into the second compartment of the Petri dish. Add three drops of phenolphthalein indicator solution and stir to mix.
10. Repeat steps 5–7 for the electrolysis of sodium chloride solution. Record observations in the data table.
11. After electrolysis, add 3 drops of potassium iodide solution, followed by one drop of starch, to the sodium chloride solution. Record observations in the data table.
12. Carefully pour about 8 mL of 0.2 M copper(II) bromide solution into the third compartment of the Petri dish.
13. Repeat steps 5–7 for the electrolysis of copper(II) bromide solution. Record observations in the data table.
14. Remove the pencil lead electrodes from the alligator clips and disconnect the battery cap from the battery.
15. 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.

Electrolysis Reactions

Data Table

Electrolyte (Salt Solution)	Observations	
	Anode	Cathode
Potassium Iodide		
Sodium Chloride		
Copper(II) Bromide		

Post-Lab Questions

1. The following oxidation and reduction half-reactions are possible for the electrolysis of potassium iodide solution. The solution contains 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, citing specific evidence from your observations.

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

   *c.*Write the balanced chemical equation for the overall redox reaction in the electrolysis of aqueous potassium iodide. *Hint:* Remember to balance the electrons!

2. Using Question #1 as a guide: (a) Identify the products that were formed at the anode and the cathode in the electrolysis of sodium chloride solution, giving the specific evidence for their formation. (b) Write the balanced chemical equation for the overall redox reaction.

3. Using Question #1 as a guide: (a) Identify the products that were formed at the anode and the cathode in the electrolysis of copper(II) bromide solution, giving the specific evidence for their formation. (b) Write the balanced chemical equation for the overall redox reaction.

4. Compare the product formed at the cathode in the electrolysis of copper(II) bromide solution versus that obtained in the electrolysis of aqueous potassium iodide or sodium chloride. Explain, based on the reactivity of the metals.

5. *(Optional)* Consult a table of standard reduction potentials (E^o_{red}): Determine the minimum voltage necessary for the electrolysis of aqueous potassium iodide. *Hint:* $E^o_{cell} = E^o_{red}$ (cathode) $-$ E^o_{red} (anode)

Teacher's Notes

Electrolysis Reactions

Materials Needed *(for a class of 30 students working in pairs)*

Copper(II) bromide solution, $CuBr_2$, 0.2 M, 150 mL
Phenolphthalein indicator solution, 0.5%, 20 mL
Potassium iodide solution, KI, 0.5 M, 150 mL
Sodium chloride solution, NaCl, 0.5 M, 150 mL
Battery, 9-V, 15
Battery cap with alligator clip leads, 15
Distilled water
Paper towels
Beral-type pipets, 45
Pencil lead electrodes, 0.9-mm, 30
Petri dishes, partitioned, 15
Starch solution, 0.5%, 30 mL
Stirring rods, 15
Wash bottles, 15
Wax pencils or marking pens, 15

Safety Precautions

Copper(II) bromide solution is toxic by ingestion and may be irritating to the eyes, skin, and the respiratory tract. Phenolphthalein is an alcohol-based solution and is a flammable liquid. Keep away from flames and heat. Sodium thiosulfate acidified solution is a body tissue irritant. The electrolysis reactions will generate small amounts of hazardous gases. Perform this experiment in a well-ventilated lab only and do not breathe the vapors. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information. Remind students to wash their hands thoroughly with soap and water before leaving the lab.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Electrolysis of aqueous potassium iodide, sodium chloride, and copper(II) bromide generates halogen–water solutions. The contents of the Petri dishes should be collected in a central waste disposal beaker located in the hood. The waste beaker may be used continuously by several class sections during the day. Use a 50% sodium thiosulfate solution for disposal of the halogen water solutions according to Flinn Suggested Disposal Method #12a. The resulting waste solution should be allowed to sit overnight to thoroughly degas. It may then be rinsed down the drain with plenty of excess water according to Flinn Suggested Disposal Method #26b. Do not dispose of the electrolysis waste solutions directly down the drain.

Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12

Evidence, models, and explanation
Constancy, change, and measurement

Content Standards: Grades 9–12

Content Standard B: Physical Science, structure and properties of matter, chemical reactions, motions and forces, interactions of energy and matter
Content Standard F: Science in Personal and Social Perspectives; science and technology in local, national, and global challenges

Lab Hints

- The laboratory work for this experiment can easily be completed in a typical 50-minute lab period. The experiment works best as a follow-up to the electrolysis of water, performed as either an experiment or a demonstration. Please see "Introduction to Electrochemistry" in *Electrochemistry*, Volume 17 in the *Flinn ChemTopic™ Labs* series for directions.
- This experiment may be "supersized" for demonstration purposes by carrying out the reactions in U-tubes with carbon rod electrodes and a 6-V lantern battery as the power source. About 30–50 mL of electrolyte solution will be needed, depending on the size of the U-tubes. This method can be applied on a microscale level for the student lab. Have students make a similar U-tube small diameter glass tubing. The 9-V battery and pencil leads can be used to obtain the electrolysis products for each electrolyte solution under study.
- Students may need help correlating the color changes at the cathode in the electrolysis of potassium iodide and sodium chloride with the production of OH^- ions from the reduction of water molecules.
- The small amount of chlorine generated in the electrolysis of sodium chloride is noticeable only by a faint odor. The concentration is not strong enough to color the solution. The test for chlorine (step 11 in the *Procedure*) involves adding potassium iodide and starch to observe the formation of the familiar iodine–starch complex. Chlorine is a stronger oxidizing agent than iodine and therefore oxidizes iodide anions to iodine.
- See the experiment "All in the Family" in *The Periodic Table*, Volume 4 in the *Flinn ChemTopic™ Labs* series, for a study of the reactivity and single replacement reactions of the halogens.
- Potassium iodide solution is light- and air-sensitive. Prepare the solution fresh within two weeks of its anticipated use and store the solution in a dark bottle, if possible.
- The halogen odors generated in these reactions are very faint. The halogen odors are not a hazard when the experiment is performed as written in a well-ventilated lab. Remind students, however, never to "sniff" their experiments!
- Other electrolytes, such as silver nitrate and zinc bromide, may also be used in this experiment. Both of these metal ions are more easily reduced than the hydrogen atoms in water. Electrolysis of silver nitrate generates silver metal at the cathode. Zinc bromide gives zinc metal at the cathode and bromine at the anode.
- Universal indicator may be used as the acid–base indicator in the electrolysis of potassium iodide or sodium chloride.

Teaching Tips

- Electrolysis reactions provide a great critical-thinking exercise for students to deduce the reactions that take place. Write down all of the possible oxidation and reduction half-reactions for each salt on the board, and then have students identify the actual products based on their observations.
- Based on standard reduction potential values, oxidation of chloride ion to chlorine ($E°_{red}$ = –1.36 V) is less favorable than oxidation of water to oxygen ($E°_{red}$ = –1.23 V). However, there is a significant overvoltage for the oxidation of water, and thus chlorine is observed in the electrolysis of aqueous sodium chloride solution. The cause of the overvoltage is usually ascribed to a kinetically slow reaction at the anode. $E°_{red}$ values predict the thermodynamic tendency of a reaction to occur, not how fast or slow the reaction will be.
- 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; or (b) the modern importance of electrolysis in the production of industrial chemicals, including aluminum, sodium hydroxide, chlorine, etc.

Answers to Pre-Lab Questions *(Student answers will vary.)*

1. Complete the following table summarizing the general properties of the electrodes in an electrolytic cell.

Electrode	Oxidation or Reduction	Sign of Electrode
Anode	Oxidation	Positive
Cathode	Reduction	Negative

2. Sodium metal is produced commercially by the electrolysis of molten sodium chloride. The by-product of the reaction is chlorine gas. (a) Write the oxidation and reduction half-reactions for the electrolysis of molten sodium chloride. (b) Identify the substance that is oxidized and the substance that is reduced. (c) Write the balanced chemical equation for the overall reaction.

   a. Oxidation half-reaction (anode) $2Cl^{-}(l) \rightarrow Cl_2(g) + 2e^{-}$

   Reduction half-reaction (cathode) $Na^{+}(l) + e^{-} \rightarrow Na(l)$

   Note to teachers: *Sodium metal is a liquid at the temperature required for the electrolysis of molten sodium chloride.*

   b. Chloride anions are oxidized to chlorine gas; sodium cations are reduced to sodium metal.

   c. Overall balanced equation $2NaCl(l) \rightarrow 2Na(l) + Cl_2(g)$

   Note to teachers: *Remind students about the need to balance electrons as well as atoms and charge when balancing the chemical equation for a redox reaction.*

3. Sodium metal is easily oxidized—it is a very reactive metal. Sodium reacts spontaneously with water at room temperature to give sodium hydroxide and hydrogen gas. Would you expect to observe sodium metal in the electrolysis of aqueous sodium chloride? Explain.

The fact that sodium is very reactive and easily oxidized suggests that it should be extremely difficult to reduce sodium cations. In aqueous sodium chloride solution, therefore, reduction of water to hydrogen gas should be more favorable than reduction of sodium cations to sodium metal. Sodium metal will not be generated in the electrolysis of aqueous sodium chloride.

Sample Data Table *(Student data will vary.)*

Electrolyte (Salt Solution)	Observations	
	Anode	**Cathode**
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.
Sodium Chloride	Slow bubbling at positive electrode—very faint odor of chlorine (swimming pool smell). Solution turned dark blue when potassium iodide and starch solution were added.	Rapid gas bubbling observed at negative electrode. Solution immediately surrounding the cathode turned bright pink.
Copper(II) Bromide	Rapid bubbling observed at positive electrode. Solution around anode turned yellow (original color was blue-green). Strong odor.	Dark solid deposited on negative electrode. The color of the solid was not obvious until the electrode was removed—reddish brown solid. Solid easily rubbed off on paper towel.

Answers to Post-Lab Questions *(Student answers will vary.)*

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

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

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

   a. What product was formed at the anode in the electrolysis of potassium iodide solution? Explain, citing specific evidence from your observations.

   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 by-product.

   c. Write the balanced chemical equation for the overall redox reaction in the electrolysis of aqueous potassium iodide. *Hint:* Remember to balance the electrons!

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

2. Using Question #1 as a guide: (a) Identify the products that were formed at the anode and the cathode in the electrolysis of sodium chloride solution, giving the specific evidence for their formation. (b) Write the balanced chemical equation for the overall redox reaction.

   a. The substance formed at the anode (oxidation product) is a water-soluble gas with a "swimming pool" odor—chlorine. The dark yellow color observed when potassium iodide was added is due to iodine. (Chlorine oxidizes iodide ions to iodine.) The substance formed at the cathode (reduction product) is hydrogen. Hydroxide ions are formed as a by-product. See the observations and explanation for electrolysis of potassium iodide.

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

3. Using Question #1 as a guide: (a) Identify the products that were formed at the anode and the cathode in the electrolysis of copper(II) bromide solution, giving the specific evidence for their formation. (b) Write the balanced chemical equation for the overall redox reaction.

   a. The substance formed at the anode (oxidation product) is a dark yellow, water-soluble liquid with a sharp odor—bromine. The substance formed at the cathode (reduction product) is a reddish brown solid— copper metal.

   b. $Cu^{2+}(aq) + 2Br^-(aq) \rightarrow Cu(s) + Br_2(aq)$

4. Compare the product formed at the cathode in the electrolysis of copper(II) bromide solution versus that obtained in the electrolysis of aqueous potassium iodide or sodium chloride. Explain, based on the reactivity of the metals.

   Copper metal was obtained at the cathode (reduction product) in the electrolysis of copper(II) bromide solution. This contrasts with the formation of hydrogen as the reduction product in the electrolysis of aqueous potassium iodide or sodium chloride. Copper(II) ions are therefore more easily reduced than water molecules or potassium or sodium ions The ease of reduction: $Cu^{2+} > H_2O >> Na^+, K^+$. *Potassium and sodium are very reactive metals—they are easy to oxidize, their cations are difficult to reduce. Copper metal is a relatively unreactive metal—it is harder to oxidize, but its cations are easy to reduce.*

5. *(Optional)* Consult a table of standard reduction potentials (E^o_{red}): Determine the minimum voltage necessary for the electrolysis of aqueous potassium iodide. *Hint:* $E^o_{cell} = E^o_{red}\text{ (cathode)} - E^o_{red}\text{ (anode)}$

   Oxidation (anode): $2I^-(aq) \rightarrow I_2(s) + 2e^-$ $\qquad$ $E^o_{red} = +0.54\ V$

   Reduction (cathode): $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ $\qquad$ $E^o_{red} = -0.83\ V$

   $E^o_{cell} = E^o_{red}\text{ (cathode)} - E^o_{red}\text{ (anode)} = -0.83\ V - 0.54\ V = -1.37\ V$

   The minimum cell voltage required for this nonspontaneous reaction is 1.37 V.

   Note to teachers: *E° values are based on 1 M solutions of all ions, which was not the case in this experiment.*

Reference

This lab was adapted from *Electrochemistry*, *Flinn ChemTopic™ Labs*, Vol. 17, Cesa, I., Editor; Flinn Scientific Inc.: Batavia, IL (2005).

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Electrolysis of Potassium Iodide* activity, presented by Bob Lewis, is available in *Electrolysis Reaction*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Electrolysis of Potassium Iodide* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Electrolysis Reactions—Oxidation and Reduction* kit available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6894	Electrolysis Reaction—Oxidation and Reduction
AP1430	Transistor Battery (Alkaline) 9V
C0279	Copper (II) Bromide
P0066	Potassium Iodide
P0019	Phenolphthalein Indicator Solution
S0061	Sodium Chloride
S0302	Starch, Spray
AP1817	Pencil Leads
AB1472	Petri Dish, Disposable, Partitioned
AP1516	Pipets, Beral-Type
AP8954	Battery Clips with Alligator Clip Leads

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