2.5 The Electrolytic Cell

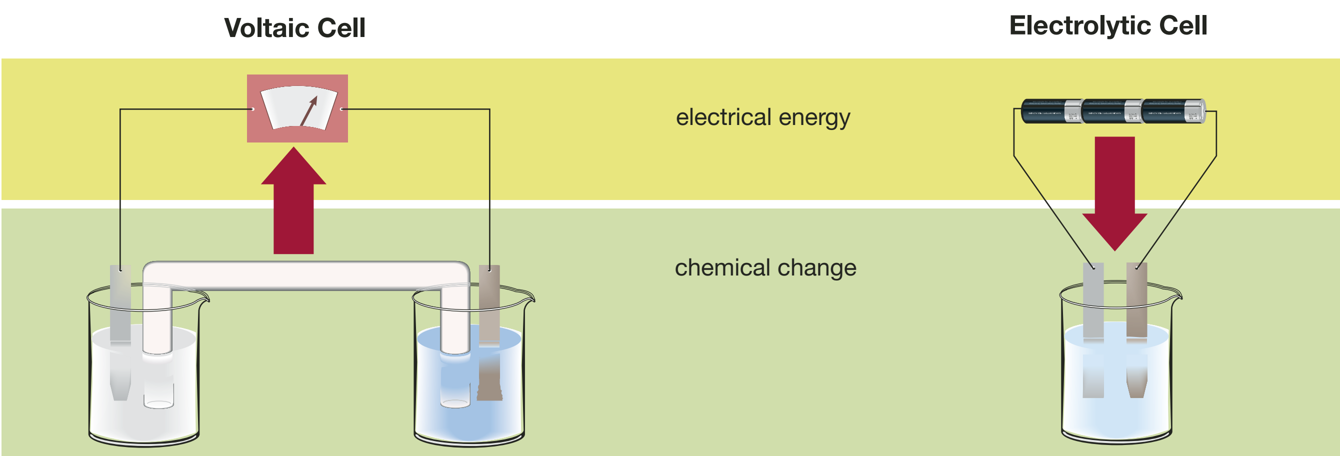
Figure A2.26: Iron is an easy victim for corrosion if left unprotected.

electrolytic cell: a chemical system in which non-spontaneous oxidation and reduction reactions are made to occur by the application of electrical energy

You use metals every day. However, most metals are reactive and will oxidize to produce metal ions. With this reaction, they will eventually return to the earth, combining with other substances to reform the ionic compounds from which they came.

As indicated by their position in the activity series, gold and silver are two metals that do not oxidize as easily as other metals. This makes them extremely valuable because objects made from these metals will resist corrosion and probably last a long time. Unfortunately, it is usually too expensive to make an object entirely of these precious metals.

A cost-effective alternative is to apply a very thin coating of a corrosion-resistant metal to the surface of a susceptible metal. These protective coatings are applied using a variation of the voltaic cell called the **electrolytic cell**. Both cells involve chemical change and electrical energy.



The difference between these cells is that a voltaic cell uses chemical change to produce electrical energy, whereas an electrolytic cell uses electrical energy to produce a chemical change.

You can observe a very simple electrolytic cell in operation in the next activity.

Try This Activity

Using Electrical Energy to Force Chemical Change

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will observe the effect of an electric current through water. A small amount of sodium sulfate is added to the water as an electrolyte to improve its ability to conduct electricity.

Materials

- 500-mL beaker
- 9-V battery
- matches
- wood splints
- stirring rod
- 28.0 g of sodium sulfate, $Na_2SO_4(s)$
- 400 mL of distilled water
- 2 test tubes (15 mm × 150 mm)
- test tube rack

CAUTION!
Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Add 28.0 g of sodium sulfate, $Na_2SO_4(s)$, into a beaker containing 400 mL of water, and stir to dissolve the solute.

step 2: Once the sodium sulfate has dissolved, fill each test tube to the very top with the solution and place it in a test tube rack.

step 3: Place a new 9-V battery into the remaining solution in the beaker. The battery should be sitting on the bottom of the beaker, completely submerged in the solution, with the terminals facing upward.

step 4: Observe each terminal of the battery for evidence of chemical change. You should see some gas bubbles appearing at each terminal. Can you predict the gases that are produced?

step 5: To collect the gas produced at each terminal, take the two test tubes filled with the electrolyte solution and cover the tops with your thumbs. Carefully tip the test tubes over, and slowly remove your thumb once they are under the surface of the solution. Position each test tube so the opening covers one of the battery terminals.

step 6: After a few minutes, note whether one tube is filling with gas faster than the other.

step 7: Given that the chemical formula for water is $H_2O(l)$, determine which of the test tubes contains hydrogen gas and which contains oxygen gas.

step 8: Remove the test tube you think contains hydrogen gas. Do this by placing your thumb over the open end of the test tube and carefully removing each test tube without losing the gas collected. While pointing the open end of the test tube in a safe direction, use a **burning** splint to confirm your prediction.

step 9: Remove the test tube you think contains oxygen gas using the same method stated in step 8. While pointing the open end of the test tube in a safe direction, use a **glowing** splint to confirm your prediction in this case.

Analysis

1. In this activity, you assembled a simple electrolytic cell.
   a. Identify the source of electrical energy for this cell.
   b. Describe the evidence that indicates that this electrolytic cell caused a chemical change.
2. Consider the gas collected in the test tube positioned over the positive terminal of the battery. What does the splint test indicate about the identity of this gas?
3. Consider the gas collected in the test tube positioned over the negative terminal of the battery. What does the splint test indicate about the identity of this gas?
4. More gas accumulated in one of the test tubes than in the other. State the identity of this gas, and use the following chemical reaction to help you explain why a larger amount of it was produced.

   $2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$
5. In this activity you added a salt, sodium sulfate, to act as an electrolyte so that the distilled water could conduct electricity. Concisely explain why both voltaic and electrolytic cells require electrolytes to properly function.

Using Electrical Energy to Produce Metal Coatings

Many metal products manufactured today have a thin coating of a less corrosive metal added to their surface. In this process, the object to be coated is submerged in a solution containing metal ions that will eventually form the corrosion-resistant surface. An external source of electrical energy supplies energy to electrons that flow through two electrodes: one electrode connects to the object to be coated and the other to a second electrode in the conducting solution to complete the circuit. This process is called **electroplating**.

You will have an opportunity to build an electrolytic cell that can electroplate copper onto a carbon electrode in the next investigation.

electroplating: the process of depositing a metal at the cathode of an electrolytic cell

Figure A2.27: Large-scale industrial electroplating facilities use banks of electrolytic cells to produce metal coatings.

Investigation

Electroplating Copper

Purpose

You will assemble an electrolytic cell that will add a thin coating of copper to a carbon electrode. You will observe changes to the electrodes that will verify that chemical change has occurred.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Materials

- 150 mL of 0.250-mol/L copper(II) sulfate solution, $CuSO_4(aq)$
- 2 electrical leads with alligator clips
- 9-V battery (or direct current power supply)
- carbon electrode
- copper electrode
- 250-mL beaker
- electronic balance

CAUTION!

Use gloves, safety glasses, and a lab apron for this investigation. Copper(II) sulfate solution, $CuSO_4(aq)$, is toxic and an irritant.

CAUTION!

Proceed with caution if you are using a direct current power supply. An ammeter should be used to ensure that the current does not exceed 2.0 A. The power supply should be protected by a fuse or circuit breaker in case the electrodes accidentally touch.

Procedure

step 1: Before starting this investigation, carefully read over the entire investigation. Design a data table to record the qualitative and quantitative observations you will make during the investigation.

step 2: Pour 150 mL of 0.250-mol/L copper(II) sulfate solution into the beaker.

step 3: Measure the initial masses of the carbon and copper electrodes, and record each value in your data table.

step 4: Take the carbon electrode and attach an alligator clip to one of its ends. Take the other end of the alligator clip and attach it to the negative terminal of the 9-V battery (or to the negative terminal of the power supply).

step 5: Take the copper electrode and attach an alligator clip to one of its ends. Take the other end of the alligator clip and attach it to the positive terminal of the 9-V battery (or to the positive terminal of the power supply).

step 6: Carefully place the electrodes into the copper(II) sulfate solution. Do not immerse the alligator clips or let the electrodes touch each other.

step 7: Let the electrodes sit in the solution for approximately 10 min. During this time, look at the electrodes and note any changes you see.

step 8: Disconnect the alligator clips from the battery and the electrodes. Observe any changes to the electrodes that have occurred.

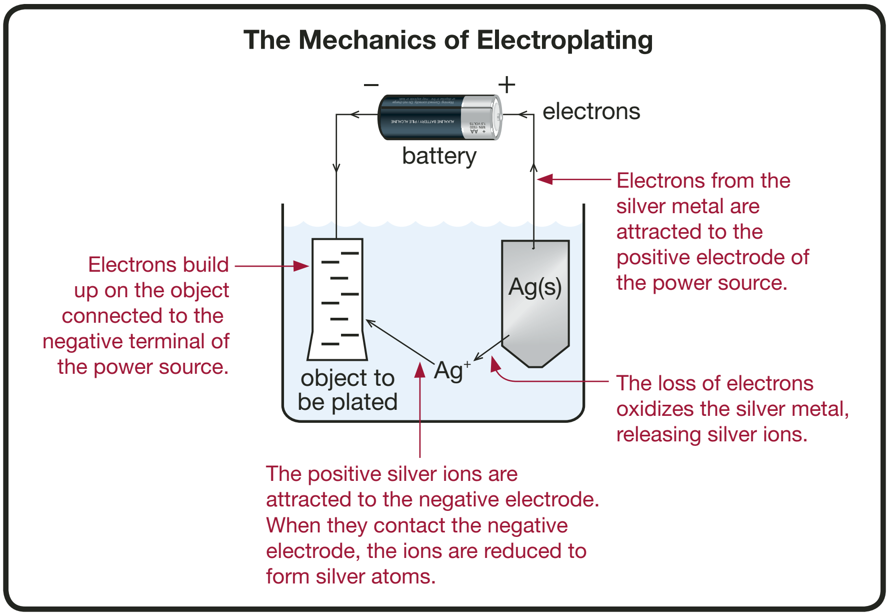
step 9: Allow the electrodes to dry thoroughly, and measure the final mass of each electrode. Record the values in your data table.

Analysis

1. Describe any changes that occurred at the carbon electrode.
2. Describe any changes that occurred at the copper electrode.
3. Identify the evidence that indicates a reduction half-reaction occurred during the operation of the electrolytic cell. Write the half-reaction that describes this reaction.
4. Identify the evidence that indicates an oxidation half-reaction occurred during the operation of the electrolytic cell. Write the half-reaction that describes this reaction.
5. Draw a diagram of the apparatus. Label the anode, the cathode, the electrolyte, and the direction of electron flow provided by the power source.

A Look into Electroplating—The Mechanics of an Electrolytic Cell

Earlier, you explored the idea that batteries make use of spontaneous oxidation and reduction reactions. Energy is released as relatively reactive metals lose electrons to relatively reactive ions. The resulting current of electrons is guided through a wire so that their energy can be captured and used by your electronic devices.



Electroplating, however, is a process that forces non-spontaneous oxidation and reduction reactions to occur. Energy is used to remove electrons from the metal located at the anode of the cell and transfer them to metal ions within the electrolyte near the cathode of the cell. The cell you constructed in the last activity forced copper(II) ions in the solution to gain electrons and become copper metal. Cells like this can be used to electroplate one metal over another metallic substance. Can you think of a reason why this process is an effective way to protect metals that tend to be easily oxidized?

Electroplating is commonly used to protect metals from other elements in the environment that might cause corrosion. Iron and other metals are often electroplated with chromium, platinum, silver, or gold to protect them from substances in the atmosphere that oxidize them. Electroplating a metal can increase the life span of the consumer good without having to actually make the entire object out of an expensive metal.

Practice

Use the following information to answer questions 44 to 46.

Gold Used in Jewellery

If an object is made entirely from pure gold, it is described as being made from 24-karat gold. However, because gold is such a soft metal, it is often combined with other metals, like brass (copper and zinc) and nickel, to make the object more durable. A piece of jewellery made from 18-karat gold is 75% pure gold, and a piece that is 12-karat gold is only 50% pure gold. By law, every piece of jewellery has to be stamped with the karat or (k) mark, along with the manufacturer's trademark.

Gold-filled jewellery is also called gold overlay or gold clad. These pieces have a layer of at least 10-karat gold that has been permanently welded to a less expensive metal underneath. The karat gold must make up at least 1/20 of the total mass of the piece in order to qualify as gold-filled. Gold-filled items, like designer frames for eyeglasses, have many of the advantages of a gold surface without the excessive weight characterized by 24-karat gold.

Jewellery that is gold-plated means that an electrolytic cell was used to coat the surface with a plating of at least 10-karat gold. The coating on the surface is much thinner than it is for rolled gold, so these pieces are not as durable. This process is ideal for pieces that have intricate designs or are very large.

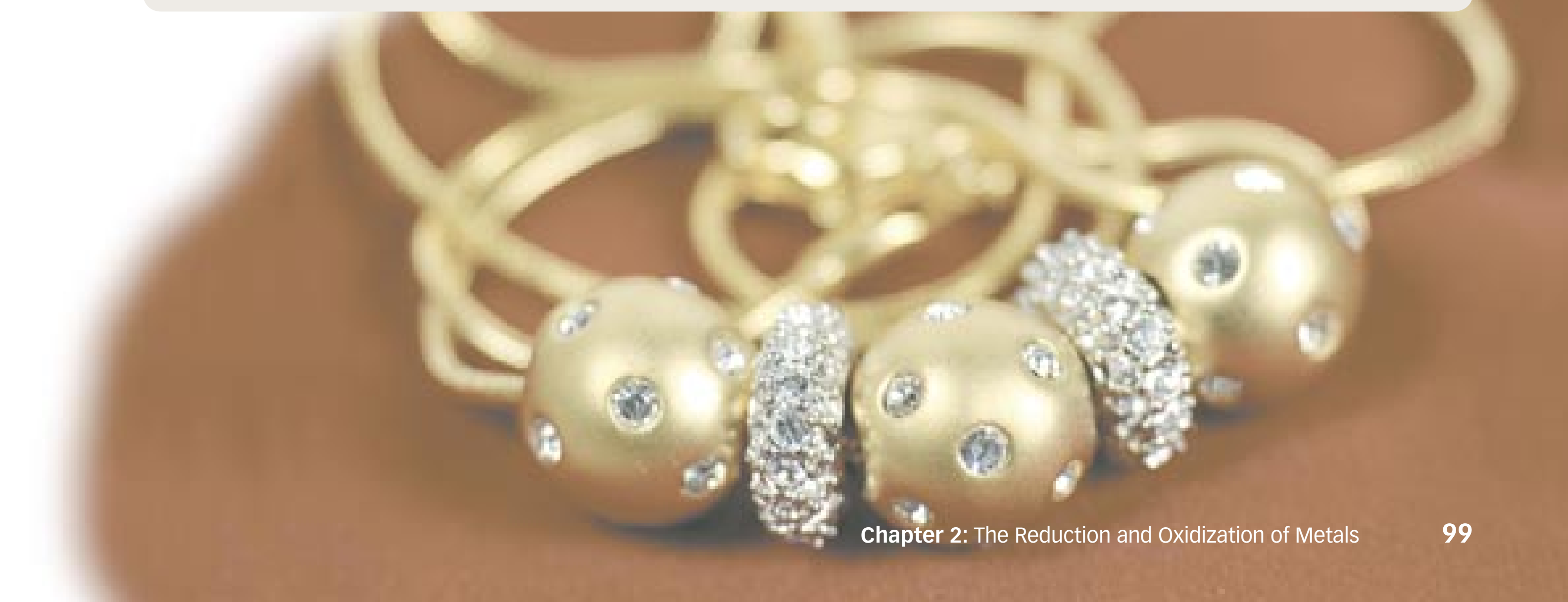
44. Consider the following description of a bracelet being sold:

"For Sale: One gold bracelet, 15 cm long, $200."

If you were interested in buying this item, what questions should you ask the seller?

45. In a commercial gold-plating operation, would you expect the piece of jewellery to be electroplated to be in contact with the negative terminal of the power supply or with the positive terminal? Explain your reasoning.

46. Gold-plating is a cost-effective alternative to the other types of gold jewellery because the gold can be applied sparingly to the surface. However, care must be taken not to scratch this thin layer. Explain the problems created by deep scratches on the surface of gold-plated objects.



Other Uses for Electrolytic Cells

Refining Metals

Recall that when copper is extracted from its ores, blister copper is produced from molten copper sulfide. Blister copper is 97% to 99% pure copper. Although this grade of copper is fine for many applications, it is still not pure enough for use in copper wires. Copper wire must be 99.99% pure copper. Further refinement is done using an electrolytic cell.

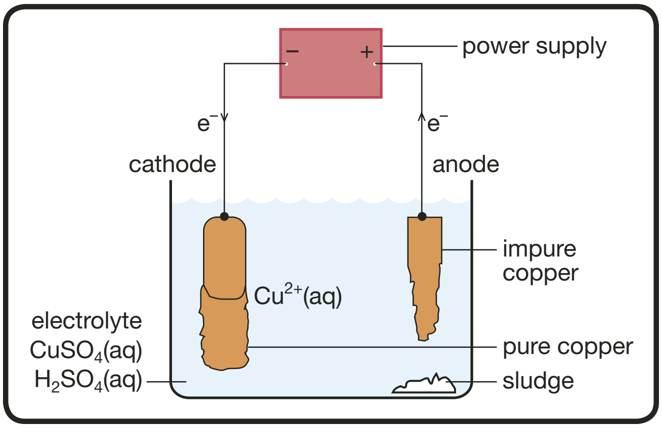


Figure A2.28: This electrolytic cell shows purifying copper.

In Figure A2.28, a very thin electrode of already pure copper is connected to the cathode. The blister copper is attached to the anode. As the copper in the blister copper is oxidized at the anode, copper ions, $Cu^{2+}(aq)$, are released and enter the solution. The free-floating, positive copper ions diffuse in the solution and are eventually attracted to the electrons at the cathode. They move toward the cathode and gain two electrons when they come into contact with it. By gaining two electrons, the copper ions are reduced to pure copper metal. Over time, the anode of impure copper shrinks while the cathode of pure copper grows.

Electrolysis

Earlier in this lesson you saw how electrolytic cells can be used to divide water molecules to form hydrogen gas and oxygen gas. This process is called **electrolysis**.

electrolysis: the decomposition of a substance by means of an electric current

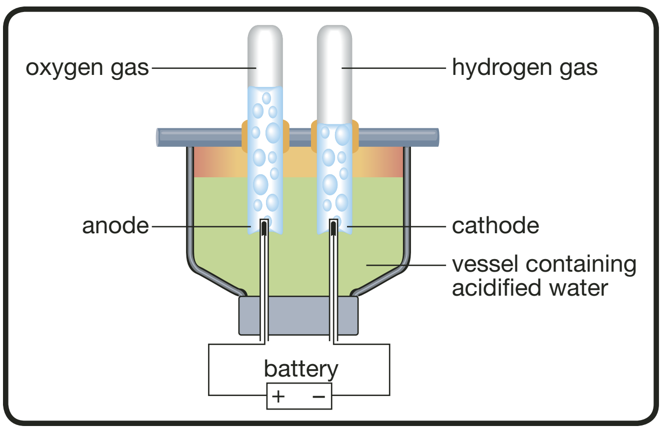


Figure A2.29: Electrolysis is actually a simple process.

In Figure A2.29, the oxygen in water molecules loses electrons at the anode to become oxygen gas, $O_2(g)$. At the same time, hydrogen in water molecules gain electrons at the cathode to become hydrogen gas, $H_2(g)$. The overall equation for this process is

$$2\,H_2O(l) \rightarrow 2\,H_2(g) + O_2(g)$$

Producing Non-Metals

Electrolytic cells are not limited to purifying only metals, they can also be used to produce non-metals.

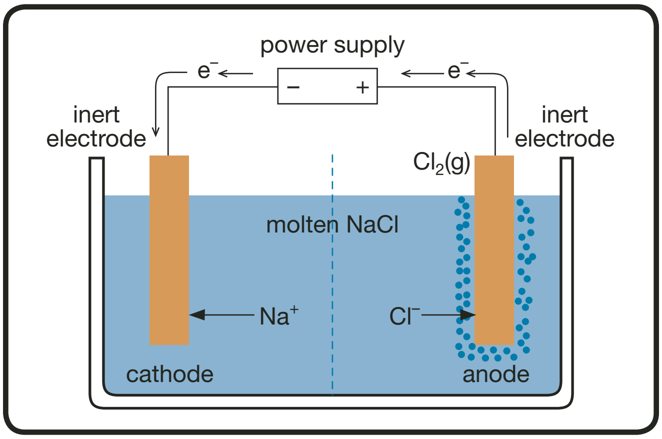


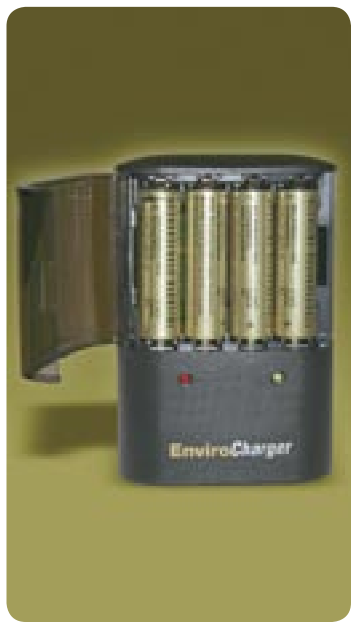
Figure A2.30: This diagram shows how an electrolytic cell produces non-metals.

In Figure A2.30, the chloride ions have electrons taken away from them at the anode to make chlorine gas. Meanwhile, the sodium ions are reduced at the cathode to produce sodium metal. Both chlorine gas and sodium metal have a large variety of industrial uses.

Chlorine is used to kill micro-organisms in both drinking water and waste-water treatment. Sodium is used as a reducing agent in refining metals like titanium.

Rechargeable Voltaic Cells

A rechargeable voltaic cell functions as an electrolytic cell when it is recharging. As mentioned earlier, a voltaic cell (or commercial cell) contains reactants that spontaneously undergo oxidation and reduction. When a cell no longer produces energy, the reactants need to be re-made. When you recharge one of these cells, you use an electric current to force the oxidation and reduction of the contents in the cell to reproduce the original reactants.



2.5 Summary

Non-spontaneous reactions require electrical energy in order for a reaction to occur. Electrolytic cells make use of non-spontaneous oxidation and reduction reactions. Electroplating is a process where you reduce metal atoms onto an object acting as an electrode. This process will give that object an outer protective layer consisting of another metal. One example is the Canadian penny. Since 1997, this coin has been made with a small percentage of copper plated over less-expensive metals. Electrolytic cells are also used to purify metals from their ores and to remove elements from compounds to produce gases.

2.5 Questions

Knowledge

1. Define the following terms.

- **a.** electrolytic cell
- **b.** electroplating
- **c.** electrolysis

2. Outline the similarities and differences between an electrolytic cell and a voltaic cell.

3. Explain the benefits of electroplating one metal with another metal.

Applying Concepts

4. Design an electrolytic cell that uses silver metal as one of the electrodes to plate a house key with silver. Be certain to include a diagram with your design that has the following components:

- electrolyte
- cathode
- anode
- loss of electrons
- gain of electrons
- negative terminal
- positive terminal
- electron flow
- products of the electrolytic cell
- power source
- oxidation half-reaction
- reduction half-reaction

5. Explain how you can purify a metal from its ore with an electrolytic cell.

6. Explain the difference between regular and rechargeable batteries.

7. Electrolysis uses an electrolytic cell to break down water molecules to form oxygen gas and hydrogen gas.

- **a.** Draw and label the important structures and products of an electrolytic cell that will complete the electrolysis of water.
- **b.** Explain why it is necessary to have an ionic compound dissolved in the water of the cell.
- **c.** Use the overall equation of electrolysis to explain how this process supports the idea that water is made up of two hydrogen atoms and one oxygen atom.

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Legend: t = top, m = middle, b = bottom, l = left, r = right

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