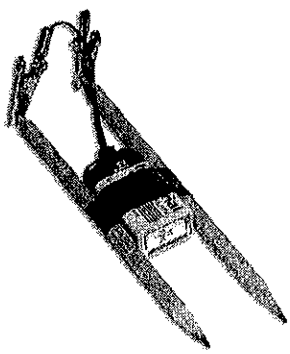
Pencil Electrolysis



Overview

Water is considered to be a rather stable compound. Adding energy in the form of heat usually causes only a change in its state; the steam that results is still H_2O. Nevertheless, ordinary materials can be used to decompose water into its elements.

Key Concepts

- chemical changes
- compounds
- conductors
- decomposition reaction
- electricity
- electrolysis
- electrolytes
- elements
- water and its properties

National Science Education Standards

Science as Inquiry Standards

Abilities Necessary to Do Scientific Inquiry

- *Students observe the formation of gas bubbles at the positive and negative electrodes as water decomposes. (5–8, 9–12)*
- *From the production of gas bubbles, students infer that water is being decomposed. (5–8, 9–12)*

Physical Science

Transfer of Energy

- *Students observe a chemical change that involves the use of electrical energy to decompose water. (5–8)*

Structure and Properties of Matter

- *Students learn that water is made of molecules, which in turn are made up of hydrogen and oxygen atoms. (9–12)*

Chemical Reactions

- *The decomposition of water involves the transfer of electrons. (9–12)*

Interactions of Energy and Matter

- *Students find that it is necessary to add compounds such as Epsom salt or Glauber's salt to the distilled water to enable the conduction of electricity. (9–12)*

Teacher Preparation

Set up the apparatus and prepare the electrolyte solution.

Materials

- pencil electrolysis apparatus (includes 9-volt battery, 2 alligator clips, 9-volt battery T-cap, and 2 number 2 pencils)

➤ *Test pencils before use. Some inexpensive pencils do not contain enough graphite to allow them to serve as electrodes.*

- water
- tape
- squirt bottle
- 1 of the following salts for an electrolyte solution:
  - magnesium sulfate heptahydrate, $MgSO_4{\cdot}7H_2O$ (Epsom salt)
  - sodium sulfate decahydrate, $Na_2SO_4{\cdot}10H_2O$ (Glauber's salt)

⚠ *Do NOT substitute NaCl (table salt) for the listed salts. Using NaCl would result in the generation of highly toxic Cl_2 gas.*

Procedure

1. Sharpen both ends of the pencils and assemble the electrolysis apparatus as shown in Figure 1.

➤ *After use, disconnect the alligator clips to prevent overheating and draining the battery. Make sure the alligator clips do not touch each other. (Attach them to the wooden part of the pencil during storage.)*

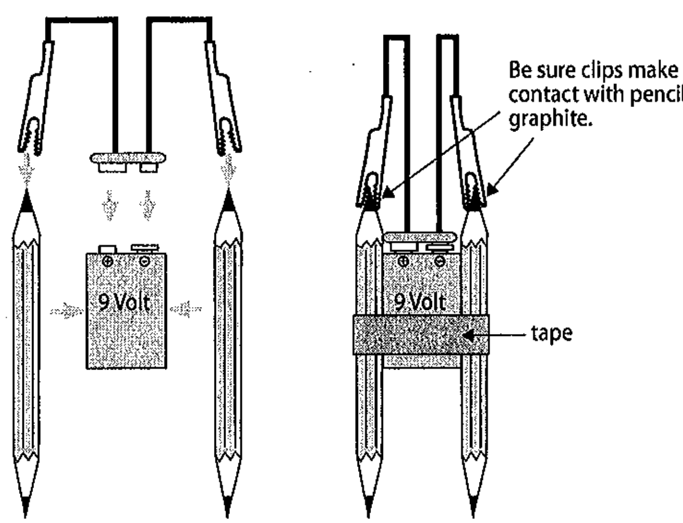


Figure 1: Assemble the pencil electrolysis apparatus.

2. Prepare about 50 mL of a saturated solution of one of the following salts to be used as an electrolyte solution in this activity.

- $MgSO_4 \cdot 7H_2O$ (Epsom salt)
- $Na_2SO_4 \cdot 10H_2O$ (Glauber's salt)

To do this, stir $MgSO_4 \cdot 7H_2O(s)$ or $Na_2SO_4 \cdot 10H_2O(s)$ into about 50 mL water until no more dissolves. Allow the mix to settle, and decant the saturated solution into a labeled squirt bottle.

Student Exploration

What does this contraption do?

Materials

- electrolysis apparatus
- shallow bowl or petri dish
- distilled water
- electrolyte solution in squirt bottle
- 5–10 drops of one of the following indicator solutions:
  - universal indicator
  - bromocresol green
  - red cabbage juice

Procedure

1. Pour distilled water to a depth of 0.5 to 1 cm in a clean, shallow bowl or petri dish.
2. Attach the battery T-cap to the battery and the alligator clips to the pencil tips.
3. Place the pencil tips (electrodes) of the electrolysis apparatus in the water. Look very closely at the submerged pencil tips. *Describe and explain your observations.* Remove the pencils.
4. Add about 5–10 drops of the indicator solution to the water so that you have an intensely colored solution, and again submerge the pencil tips. *Describe your observations.* Remove the pencils.
5. Squirt in some of the electrolysis solution and swirl it around. Place the pencil tips in the water. Observe carefully. *Record the color of the solution around each electrode. Describe what you see at each pencil tip. Is the same amount of gas being produced at both electrodes? On which side is hydrogen gas being produced? Why do you think so?*

Instructor Notes

Tips and Instructional Strategies

- Don't tell students what will happen. At the end of the activity, as students attempt to explain their observations, you may have to lead them to understand that they're "taking apart" water. Once students understand this idea, they may be able to identify which element is produced at which electrode, because they can reason that the side with twice as many bubbles must be the hydrogen side.
- Pencil electrolysis is also effective as a teacher demonstration if done on an overhead projector.
- If universal or bromocresol green indicator solution is not available, you can substitute red cabbage juice. This can be prepared by one of these methods:
    - Put approximately ¼ head of red cabbage into a blender or food processor. Add a little water and blend the cabbage into a slurry (1–3 minutes). Pour the slurry through a strainer, collecting the juice in a beaker.
    - Chop ¼ head of red cabbage and put it into a beaker. Add rubbing alcohol to cover the cabbage. Stir periodically. After about an hour, decant the liquid and discard the cabbage pieces.
- Make sure students understand the significance of the colors they see in step 5. The color changes because the pH around each electrode changes as the oxygen and hydrogen gases are produced. The pH around the cathode (negative electrode) becomes more basic because OH^- ions are produced along with $H_2(g)$. The pH around the anode (positive electrode) becomes more acidic because H^+ ions are produced along with $O_2(g)$.
- As a way for students to construct their own knowledge of the decomposition process, they can determine whether the electrode with the greater formation of a gas turns the indicator color due to excess OH^- or H^+ ions. This will allow them to identify that the electrode with greater formation of a gas is also the electrode where OH^- is produced, and the electrode where reduction occurs. Opposite arguments can be constructed for the reaction and behavior of the electrode where oxygen is formed.
- After the activity, be sure to disconnect the electrodes from the battery and to store alligator clips separately from the rest of the setup to avoid shorting out the batteries.

Explanation

Water is a chemical compound made from the elements hydrogen and oxygen in a 2:1 ratio. In this activity, water (a colorless, odorless liquid at standard temperature and pressure) is decomposed (broken apart) into its component elements, hydrogen and oxygen. Hydrogen (H_2) and oxygen (O_2) are both colorless, odorless gases at standard temperature and pressure.

The observed decomposition resulted from electrolysis (the use of electrical energy to decompose a compound). In step 3, students observed that distilled water is not a good conductor of electricity. It is necessary to add an electrolyte, such as Epsom salt (magnesium sulfate heptahydrate, $MgSO_4{\cdot}7H_2O$) or Glauber's salt (sodium sulfate decahydrate, $Na_2SO_4{\cdot}10H_2O$), to allow the electrical circuit to be completed through the solution so that the decomposition of the water in the solution can occur. The graphite in the pencils acts as the electrodes in this system. Placing the tips of these electrodes (pencils) into this electrolytic solution completes the circuit and evolution of H_2 and O_2 gas is observed at both electrodes.

The following two half-reactions represent the change taking place at the electrodes. The reduction half-reaction occurs at the cathode. The oxidation half-reaction occurs at the anode.

$$4H_2O(l) + 4e^- \rightarrow 2H_2(g) + 4OH^-(aq) \quad \text{cathode}$$
$$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^- \quad \text{anode}$$
$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g) \quad \text{overall equation}$$

Note that the equation stoichiometry predicts two moles of H_2 and one mole of O_2 will be evolved. Secondary reactions involving these reactive gases at the electrode surfaces may cause smaller amounts of the gases to actually be produced. For example, the black precipitate formed at the electrodes partially indicates these secondary reactions.

Adding an indicator solution provides students with dramatic evidence of the changes in pH surrounding each electrode. Hydroxide (OH^-) is produced around the cathode as H_2 gas is generated, creating a basic environment. The opposite is true around the anode, where the production of H^+ creates an acidic environment. The resulting color changes depend on the indicator used, as shown in the table below.

Indicator	**Neutral**	**Cathode** (where H_2 is produced)	**Anode** (where O_2 is produced)
universal	green	blue	red
bromocresol green	green	deep blue	yellow
red cabbage juice	purple	green	red

Answers to Student Questions

Step 3

No change is observed. The distilled water does not conduct electricity.

Step 4

No change is observed.

Step 5

a. Color changes will vary with the indicator used, as described in the Explanation.

b. Bubbles appear at both pencil tips (electrodes) and rise to the surface of the solution.

c. It appears that a larger volume of gas is being produced at one of the electrodes.

d. Hydrogen is being produced at the side with the larger volume of gas.

e. Water molecules contain two hydrogen atoms but only one oxygen atom.

References

Heideman, S. The Electrolysis of Water: An Improved Demonstration Procedure. *J. Chem. Educ.* **1986**, *63*, 809–10.

Kolb, K.E.; Kolb, D.K. Apparatus for Demonstrating Electrolysis on the Overhead Projector. *J. Chem. Educ.* **1986**, *63*, 517.