SN
EDUCATOR GUIDE

January 21, 2017
Charging the Future

Reduction-Oxidation Reaction Demonstration

Class time: About 15 to 20 minutes.

Purpose: This is a simple demonstration for introducing reduction-oxidation (redox) reactions.

Notes to the teacher: Please handle and dispose of copper(II) sulfate solution in accordance with federal, state and local environmental control regulations.

Materials:

- Copper(II) sulfate (available from chemical supply companies — sold as a hydrate, or sold as root killer at hardware stores)
- A large steel or iron nail/screw/bolt (or more than one if you want)
- A beaker or clear plastic cup
- A stirring rod

Directions:

1. Fill the beaker with hot water, pour in a few grams of copper(II) sulfate and stir until it dissolves. Show the students that the blue crystals of copper sulfate turn the water blue (due to Cu^{2+}). Show the students the steel (iron alloy) or iron nail, then put it in the beaker. After a few minutes, pull out the nail and show it to the students. The nail should be coated with a thin layer of reddish-bronze copper atoms, which can be easily scraped off with a paper towel. If you use more than one nail, or have a dilute enough copper(II) sulfate solution, your students may be able to notice that the blue solution gets lighter in color due to the decreasing concentration of Cu^{2+} ions.

2. Explain that the copper starts off in the solution as ions with two positive charges (having donated two electrons to sulfate), and the iron starts off as a solid composed of neutral iron atoms with the same number of protons as electrons in each atom. Since the copper has a greater affinity for electrons than the iron does, the iron loses two electrons and gets dissolved into solution. Each Cu^{2+} ion gains two electrons and becomes a solid where the iron had been. In chemistry notation, the reactions are:

   Oxidation: $Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2\ e^-$

   Reduction: $Cu^{2+}_{(aq)} + 2\ e^- \rightarrow Cu_{(s)}$

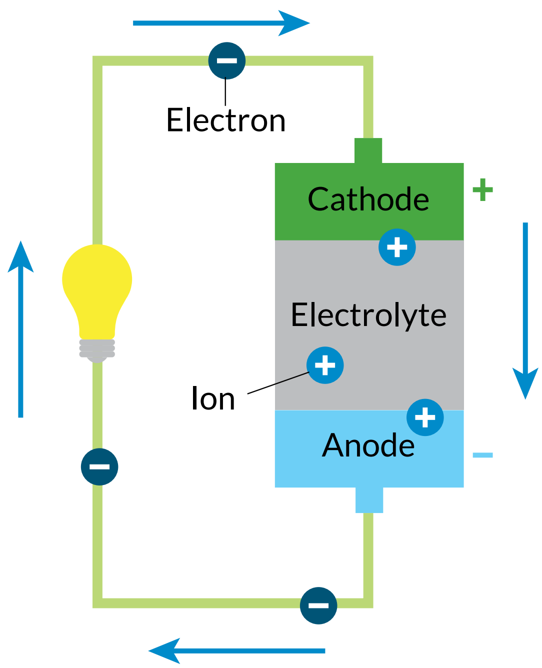
   Net reaction: $Fe_{(s)} + Cu^{2+}_{(aq)} \rightarrow Fe^{2+}_{(aq)} + Cu_{(s)}$

   The sulfate and the water were innocent bystanders in this reaction and did not directly participate. Explain that the ions, such as sulfate (SO_4^{2-}), are called spectator ions.

3. Explain that this is just one example of an oxidation and reduction reaction, but there are many others. Reduction and oxidation reactions are a mouthful to say and always occur together (electrons have to come from someplace and go to someplace), so they are called “redox reactions” for short. Also, it is important to note that the number of electrons lost in a reaction must be equal to

the number of electrons gained, so the chemical equation may need to be balanced. To remember the difference between oxidation and reduction reactions, use the mnemonic **OIL RIG**: **O**xidation **I**s **L**oss of electrons, **R**eduction **I**s **G**ain of electrons.

4. Copper wanted electrons more than iron did in this demonstration. Scientists can make a list of atoms or molecular groups in order from those that are least determined to hang on to their electrons (or in other words, those most likely to be oxidized) to those most determined to keep their electrons (or in other words, those most likely to be reduced). This difference in affinity for electrons may be expressed in terms of volts of electric potential energy, or the standard reduction potential of each material. Show an example of your favorite reduction potential table such as this one given by California State University at Dominguez Hills.



5. Using the diagram above, which also appears on Blackline Master 3, explain that a battery is a device that converts the chemical energy of a redox reaction to usable electrical energy. A battery has an anode made of one material, a cathode made of another material, an electrolyte allowing ion flow between the anode and cathode and an external electrical circuit allowing electron flow between the anode and cathode. Ignoring real-world inefficiencies and imperfections, the voltage of the battery is the difference in the standard reduction potentials of the anode and cathode materials. You may want to demonstrate calculating the difference in reduction potentials from the demonstration materials. A Khan Academy video gives a brief summary of how to calculate the overall redox reaction potentials under standard conditions from a standard reduction potential table.

Teacher Guide: What Makes Different Types of Batteries Unique?

Class time: One or two class periods plus homework

Purpose: Different student groups find and report information about different battery types

Notes to the teacher: You can adapt this activity to your preferences by including more or fewer battery types, setting the number of students per battery type, providing specific references for the students or encouraging them to do more independent research, choosing how extensive the students' research and reporting should be, and selecting how the students report their findings (public service announcement, written paper, graphical poster, oral presentation in class, computer slide presentation, etc.).

Use Blackline Master 4 to help guide your students through the battery research and summary.

Materials:

- List of battery types to research
- Books or websites for students to research battery types
- Materials for students to create posters, papers or presentations

Directions:

1. Assign different battery types to different students or groups of students. Battery types could include:
   a. Carbon-zinc batteries (older non-rechargeable batteries)
   b. Alkaline batteries (newer non-rechargeable batteries)
   c. Lead-acid batteries
   d. Nickel-cadmium batteries
   e. Lithium-ion batteries
   f. Lithium-sulfur batteries
   g. Magnesium-ion batteries
   h. Flow batteries
   i. Lithium-air batteries
   j. Sodium-sulfur batteries
   k. Hydrogen-oxygen fuel cells (similar to batteries)
2. Give students Blackline Master 4 , which lists the information they should find for their battery types.
3. Direct students to specific references for battery information, or let them do more open-ended self-directed research in the library or online. References include:
   - Online sources: Battery University and JCESR.
   - Carl H. Snyder, *The Extraordinary Chemistry of Ordinary Things*. 4th ed. New York: Wiley. 2002. Chapter 11.

- Theodore E. Brown *et al*., *Chemistry: The Central Science*. 14th ed. New York: Pearson. 2017. Chapter 20.
- *Encyclopedia Britannica*
- Wikipedia articles on specific battery types might provide a starting point to look for links to more reputable source material.

4. Let the students report their findings in the format(s) of your/their choice.

January 21, 2017
Charging the Future

Student Guide: What Makes Different Types of Batteries Unique?

Directions: Your group should take ownership of one battery type. Using the resources recommended by your teacher, find the following information for your battery (elaborate in areas where a lot of information is accessible) and summarize your findings according to your teacher's instructions.

Please be sure to include the following information:

1. Type of battery
2. Is it a primary or secondary cell (one time use or rechargeable)?
3. What is the overall redox reaction?
4. What gets oxidized (oxidation half reaction) and what gets reduced (reduction half reaction)?
5. What is the common electrolyte/ionic compound (to neutralize charge buildup)?
6. What is the voltage per cell?
7. What is the overall battery voltage, and how many cells are required to produce that voltage?
8. What is the maximum energy density in Joules per kilogram (and/or milliliter) for this electrochemical reaction? For reference, how does that compare to the energy density in Joules per kilogram (and/or milliliter) for gasoline?
9. What are the advantages of this battery type, and what aspects of the electrochemistry and battery design give it those advantages?
10. What are the disadvantages of this battery type, and what aspects of the electrochemistry and battery design give it those disadvantages?
11. What are the major applications of this battery type, and what aspects of the electrochemistry and battery design make it suitable for those applications?
12. What are the environmental concerns for the use and/or for the disposal of your battery type?
13. What is the best method of disposal for your battery type? Can it be recycled and, if so, how?
14. When and where was this battery type first developed?
15. What characteristics of this battery type could be improved, and what changes in the electrochemistry or the battery design might yield those improvements?

Teacher Guide: Building the Best Battery

Class time: 40 to 65 minutes

Purpose: Students create, test and optimize batteries using various electrodes and electrolyte compositions.

Notes to the teacher: If you have more time, you can allow the students more design options and let them figure out more things themselves. If you have less time, you can allow the students fewer design options by giving more guidance. You can order electrodes such as these from Home Science Tools or buy materials made from or coated with suitable metals from Home Depot or similar stores. Ideally students should be able to find the configurations that produce the most voltage, and then use those to light a lightbulb. If your time is limited, you could have the students focus on either the voltage measurements or lighting the bulb. This activity would work well for pairs of students working together.

Use Blackline Master 5 to help guide your students through building their batteries.

Materials:

- Beakers or clear plastic cups (about 250 ml)
- Copper electrodes (or copper tubing or stripped copper wire)
- Zinc electrodes (or zinc or zinc-plated hardware)
- Iron or steel electrodes (or iron or steel hardware)
- Aluminum electrodes (or aluminum foil or strips cut from disposable aluminum pans)
- Vinegar (5% acetic acid, sold by the gallon at many grocery stores)
- Table salt (NaCl, not iodized)
- Optional: other ionic solids to use as electrolytes such as KCl or $NaNO_3$
- Scales or balances and weigh boats or weigh paper
- Graduated cylinders
- Water (distilled if you have it, otherwise tap water)
- Stirring rods
- Electric multimeter (inexpensive models are sold at Walmart or similar stores)
- 1.5 volt incandescent lightbulbs and sockets (see this example from Home Science Tools)
- Wires with alligator clips (see for example these from American Science & Surplus)
- Table of standard reduction potentials
- Goggles
- Gloves and other protective equipment such as aprons
- Paper towels
- Sandpaper or steel wool

Directions:

1. Have the students wear goggles and gloves (and other protective equipment such as aprons, if available).

2. Show the students how to use the table of standard reduction potentials to predict the voltage difference between two different electrode materials. A Khan Academy video gives a brief summary of how to calculate the overall redox reaction potentials under standard conditions from a standard reduction potential table.

3. Show the students how to use the multimeter to measure voltage. Remind students that the multimeter leads must be in direct contact with the battery electrodes in order for the circuit to be complete. Also, when the voltage is positive, the metal electrode connected to the red lead is considered the positive terminal of the battery (the cathode) and the metal electrode connected to the black lead is the negative terminal (the anode). If the voltage is negative, the student should reverse the leads so that the voltage is positive.

4. Ideally students should determine battery configurations that produce the most voltage, and then use those to light a lightbulb. But if time is limited, determine which variables they should focus on. Students can start with determining the largest possible voltage from different combinations of electrodes (theoretically and experimentally). Once the maximum voltage is determined, students can use this electrode combination to test other variables such as the type and/or concentration of the electrolyte (how much vinegar, salt, water is in solution), the approximate distance between electrodes and the number of cells (depending on available supplies). Students can ultimately test their battery with a lightbulb. If students are more advanced, have them calculate the molarity of their electrolyte solutions.

Note the following:

Tap water may have enough impurities to make a fairly good electrolyte by itself; distilled water is less conductive and would show the students the importance of adding ions to the electrolyte. Salt (especially about 1 to 2 g per 200 ml of water) makes the water function as a much better electrolyte. Vinegar has enough ions to serve as a good electrolyte. Vinegar plus salt can be even better.

The specific electrode combination chosen will have a large effect on the voltage, generally in the ballpark of the standard reduction potentials but with some variation due to the electrolyte. (Standard conditions for the reduction potential table are defined as 25 degrees Celsius, 1 atm for any gas participating in the reaction, and 1 M concentration for each ion participating in the reaction.) The electrolyte chosen will have a smaller but still significant effect on cell potential. The spacing between the electrodes may have a small but measurable effect, depending on the electrodes, electrolyte and volume.

Show the students that they can use the alligator clip leads to connect multiple batteries in series if necessary to light a lightbulb.

SN
IN HIGH SCHOOLS
January 21, 2017

Charging the Future

Student Guide: Building the Best Battery

You can make a simple battery using a beaker or clear plastic cup partially filled with a liquid electrolyte, and with two different types of metal electrodes partially immersed in the electrolyte but not touching. You can connect the battery to a multimeter to measure voltage, or even to light a lightbulb. You can choose the electrode types, electrolyte composition, electrode spacing and other design details to optimize your results. Listen to your teacher for more specific instructions for your class.

1. Fill the beaker at least halfway with water. What is the approximate volume of water as shown on the beaker (or measure the amount of water with a graduated cylinder)?
2. Weigh out a small amount of salt between 1 and 2 grams and record the value. Stir it into the water in the beaker until it is fully dissolved. How much salt did you add?
3. Use sandpaper or steel wool to clean the electrodes before your experiment. Note how each electrode material looks before and after cleaning.
4. Using the chart below, write down the theoretically predicted voltage for each pair of electrodes using a standard reduction potential table (provided by your teacher). Note that the table is for standard cell conditions which are defined as 25 degrees Celsius, 1 atm for any gas participating in the reaction, and 1 M concentration for each ion participating in the reaction. Then put the pair of electrodes in the beaker (not touching each other) and use the multimeter to record the actual voltage between the electrodes. How much does that differ (in %) from your theoretical prediction? Make sure the distance between the electrodes remains approximately the same among all trials.

Electrode 1	Electrode 2	Theoretical voltage	Measured voltage	% difference
Copper	Copper			
Copper	Zinc			
Copper	Iron			
Copper	Aluminum			
Zinc	Zinc			
Zinc	Iron			
Zinc	Aluminum			
Iron	Iron			
Iron	Aluminum			
Aluminum	Aluminum			

5. What factors could account for differences between your measured voltages and the theoretically predicted voltages?

6. Closely observe the surfaces of the electrodes after you remove them from the electrolyte. What do you see? What caused what you see? After your experiments, be sure to dry the electrodes and then clean them with sandpaper or steel wool.

7. Can you improve the performance by adjusting the spacing between electrodes? Record your results.

8. Can you improve the performance by using a different electrolyte? Try larger or smaller amounts of salt, different mixtures of water and vinegar ranging from pure water to pure vinegar, etc. Refer to your teacher for more specific instructions. Record your results.

9. Can you light a lightbulb with your battery? If one battery cannot produce enough voltage, you can connect two or more batteries in series (the positive terminal of one battery to the negative terminal of the next battery). Record what setup works best.

10. Summarize your results. What conditions were optimal for creating a battery that produced the highest voltage?

11. Reflect on your experimental quest for making the best battery. What did you enjoy about it? What made it difficult? After reading “Charging the future,” how do you think your experience compares to the challenges battery scientists face?