Lesson Plan: Exploring Automotive Corrosion

FOR THE TEACHER

Summary
In this lesson, students will investigate the galvanic corrosion that can occur when different metals come in contact with each other in modern cars.

Grade Level
High School

NGSS Alignment
This lesson will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-2**: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- **HS-PS1-7**: Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
- **HS-ETS1-3**: Evaluate a solution to a complex real-world problem based on priorities criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

AP Chemistry Curriculum Framework
This lesson plan supports the following units, topics, and learning objectives:

- **Unit 4: Chemical Reactions**
  - **Topic 4.7**: Types of Reactions
    - TRA-2.A: Identify a reaction as acid-base, oxidation-reduction, or precipitation.
  - **Topic 4.9**: Oxidation-Reduction (Redox) Reactions
    - TRA-2.C: Represent a balanced redox reaction equation using half-reactions.

Objectives
By the end of this lesson, students should be able to

- Describe galvanic corrosion in terms of electron flow.
- Explain galvanic corrosion in reference to the activity series of metals.
- Write half-reactions for oxidation and reduction of metals.
- Explain how electrolytes such as road salt promote corrosion.

Chemistry Topics
This lesson supports students’ understanding of

- Chemical Reactions
- Chemical Change
- Ionic compounds
- Electrolytes
- Activity Series of Metals
- Oxidation
- Reduction
Time
Teacher Preparation: 3 hours (This is a one-time event to prepare the materials). After that, repeats of the lesson should take less than 30 minutes of preparation. See Teacher Notes for additional information.

Lesson: 90 minutes
- Engage: 15 minutes
- Explore: 30 minutes
- Explain: 15 minutes
- Elaborate: 45-60 minutes
- Evaluate: 30 minutes (could be several days or weeks later at end of unit)

Materials
For each group
- 1 Aluminum bar 1” x 96” x 1/8” (cut into 6-inch lengths, 4 holes pre-drilled)
  - 1 bar makes 16 fixtures
- 1 Steel bar 1” x 96” x 1/8” (cut into 6-inch lengths, 4 holes pre-drilled)
  - 1 bar makes 16 fixtures
- 500mL of 1 M solution NaCl, CaCl₂, MgCl₂, and distilled water for the control
- 4 Spray Bottles (1 for each salt solution and 1 for distilled water)
- Pan Head Bolts with matching nuts: ¼” x 20 – ¾” long.
  (Need a set of stainless steel, chrome, brass, zinc)
  - Need 1 bolt + 1 nut in each material
  - See assembly below

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.

Teacher Notes
- This lab is designed to show the different forms of corrosion that occur in modern cars. Today’s cars are made from various different metals, including aluminum, steel, brass, copper, chrome, and zinc. In particular, body panels and frames are made mainly from steel and aluminum. Although these are great materials for body parts, they don’t make good fasteners, so cars are often bolted together with bolts and rivets made from different metals, such as stainless steel, zinc, or chrome. Wherever different metals make contact with each other, galvanic corrosion can occur. Students will observe galvanic corrosion in this activity, facilitated by the presence of road salt (NaCl, MgCl₂ or CaCl₂). You can use all the salts or just the one typically used in your region. If you live near the coast, seawater would be a great electrolyte. Students will see
different galvanic corrosion rates based on the salt applied, and how the salt corrodes different metals at different rates. Salt facilitates the transfer of electrons, so it should speed up the corrosion quite nicely.

- If you don’t have access to power tools or don’t feel comfortable creating the hardware pieces, consider partnering with an Industrial Tech teacher in your building and see if students taking Industrial Tech can fabricate them for you. It would also be great to have students in Industrial Tech follow the experiment or even do one on their own to see how their work can connect to science content. If this doesn’t work for you, many Home Depot and other hardware stores will cut the metal bars to size. (See Materials Section for sizing info)

- Many of the hardware pieces, including the aluminum and steel bars, can be purchased at any hardware store. Specialty metal hardware, such as chrome, aluminum, titanium, and many others are expensive, but can be found online. One good source is www.boltdepot.com.

- Standard hardware-store materials for 16 fixtures (8 in each material) can be obtained for around $60.00 and most of these materials can be used more than once. Also, for faster results, the corrosion reactions can be sped up significantly by alternatively spraying with the salt solutions then suspending over a hot plate to around 50°C.

- This lab can be used as part of Chemical Reactions (Single Replacement and Activity Series of Metals) or Ionic compounds (salts as electrolytes).

- **Engage**: Show CarWow Article about car materials. It is full of full-color photos of sports cars and includes relevant information about the metal components of modern cars. In addition, show pictures of rusted out cars (How exactly does salt rust cars?) to get buy-in regarding the topic.

- **Explore**: Students review Activity Series of Metals, complete the guided simulation, answer questions, and share their findings in a jigsaw activity. Assemble hardware, make solutions. Students develop hypotheses of corrosion interactions (galvanic) and predict which will corrode most on its own in the presence of road salt.

- **Explain**: Students explain their hypotheses based on activity series of metals and prior knowledge of electrolytes. Teacher explains RedOx chemistry that leads to corrosion. Reduction and oxidation instruction takes place over a period of days or weeks while metals react with each other and the salt solutions. Findings are collected at the end of unit.

- **Elaborate**: Teacher explains RedOx chemistry that leads to corrosion. Reduction/Oxidation instruction takes place over a period of days or weeks while metals react with each other and the salt solutions. Students learn half-reactions, oxidation, reduction, other aspects of electrochemistry during this time. Findings are collected at the end of unit. At the conclusion of the investigation, have students complete this simulation within student conclusion section of handout to enhance their understanding of RedOx reactions.

- **Evaluate**: Students collect data (qualitative and quantitative) during this time. At the conclusion of the unit, evaluate the metals and explain results. Thoughtful post-lab questions can be used to assess student learning. Students can also present their findings and conclusions to the class.
• **Expected Results:**
  
  o  **Aluminum Sample Results (no heat added)**

  **24 hours**

  ![Image of aluminum samples after 24 hours]

  **96 hours**

  ![Image of aluminum samples after 96 hours]

  **7 days**

  ![Image of aluminum samples after 7 days]
FOR THE STUDENT

Lesson

Exploring Automotive Corrosion

Background
As a chemistry student, you already know how cool cars are, and you may even drive one of your own. Today's cars are made of a variety of metals, including steel, aluminum, copper, and chrome. While only steel (iron) actually rusts, whenever two different metals are placed in contact with each other, corrosion can occur. This type of corrosion is known as galvanic corrosion and it occurs because of the flow of electrons from more active metals to less active ones. Remember learning about the Activity Series of Metals? Well, this is why it actually matters to you and to your car.

Pre-lab
Students should use the following resources to answer the Pre-Lab Questions:
- Document A: How exactly does road salt cause cars to rust?
- Document B: Car Materials Explained
- Document C: Bitesize Chemistry on Oxidation and Corrosion
- Document D: Khan Academy RedOx Reaction Basics
- Document E: Activity Series of Metals
- Document F: Aluminum Design.net - Aluminum Corrosion Resistance

Questions:
1. Define the following terms:
   a) Oxidation:
   b) Rusting:
   c) RedOx reaction:
   d) Galvanic corrosion:
   e) Electrolyte:
   f) Half-reaction:

2. What metals are most commonly used in automotive parts?

3. What metals are most susceptible to oxidation (corrosion) and why?

4. How do electrolytes influence corrosion of metals?

5. Which metals do you expect to corrode? Include a prediction for each combination in your data table.

Objectives
- The purpose of the lab is to observe galvanic corrosion between different metals, and investigate how road salt corrodes the metals in your car.
- You will investigate galvanic corrosion using aluminum and steel with fasteners of different metals to simulate the metal interactions in cars. You will also expose
them to different road salts (NaCl, MgCl₂, CaCl₂) and investigate how road salts affect corrosion of different metals.

**Materials**  
(Per lab group):
- 1 Aluminum bar
- 1 Steel bar
- 500mL of 1M NaCl solution
- 500mL of 1M CaCl₂ solution
- 500mL of 1M MgCl₂ solution
- Distilled water
- 600 mL beaker or Spray Bottle for each salt solution
- Pan Head Bolts with matching nuts (1 bolt + 1 nut in each material)

**Safety**
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- When you complete the lab, follow your teacher’s instructions about how to clean up your materials and dispose of any chemicals.

**Procedure**
**Assembling the apparatus**

1) Select a nut and bolt from each material and screw the nut on the bolt. Measure the mass of each set of 2 (nut + bolt) together and record it in your data table.
2) Place the bolt in the hole and tighten the nut to ensure a good contact between the hardware and the bar.
3) Label each end of the bar with a sharpie (#1-4) and create a data table that lists each metal.
4) Prepare a 1M solution of your salt (NaCl, MgCl₂, or CaCl₂). Transfer the salt solution to a spray bottle and label it carefully. The label should list the name (in words) and the concentration (1M).
5) Place your setup on a paper towel with the names of your group members
6) You may want to take a picture of your setup so you can see changes as they occur over time. Some changes may be subtle, so pictures are especially helpful for determining if a change has taken place.
7) At the end of the experiment, carefully remove the nut and bolt from each bar and use a balance to determine the mass of them together. Record this new mass in your data table.
Results
Create a data table to record your data. An example is shown below. You may want to create additional rows or columns, depending on which hardware or salt you use.

<table>
<thead>
<tr>
<th>Bar</th>
<th>Salt</th>
<th>Stainless Steel</th>
<th>Zinc</th>
<th>Brass</th>
<th>Chrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex: Aluminum</td>
<td>NaCl</td>
<td>Prediction:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrode?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The metal or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>the hardware?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mass Initial:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mass Final:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Observations:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculations
Calculate change in mass and % change for each hardware + metal combination. Organize and show your work below.

- The change in mass from the chemical reaction during the experiment can be determined by: $\text{Mass}_{\text{final}} - \text{Mass}_{\text{initial}} = \text{Change in mass}$
- A positive value for change in mass indicates that the hardware gained mass during the experiment
- A negative value for change in mass indicates that the hardware lost mass during the experiment.

Analysis
1. Qualitative Analysis: In your data table, describe the changes you see for each combination. What is corroded? The bolt, the plate, or neither? Describe the changes in as much detail as you can.

2. Quantitative Analysis: Carefully remove the bolts and record the mass of the nut + bolt in your data table. This is the final mass

3. Percent change should be calculated for each combination.

Conclusion
Now that you’ve completed the investigation, extend your understanding further with this simulation. Pay particular attention to the transfer of electrons that takes place during the RedOx reactions.

1. a. Which metal is losing electrons?
   b. Which is gaining electrons?
   c. What patterns can you see?
2. Automobile makers are using more Aluminum in modern cars to decrease vehicle weight and improve vehicle efficiency. They claim that Aluminum doesn’t rust. Are they correct? Explain your answer using data from your lab.

3. How can we explain what’s happening on a microscopic level? What is the chemistry of rusting/corrosion? Consider the galvanic corrosion that takes place when copper and zinc are in contact with each other. Write half-reactions for the oxidation and reduction reactions.

4. Cars are held together by a variety of nuts and bolts, made of different metals. How can carmakers prevent galvanic corrosion between sheet metal and fasteners when they are made of different metals? Propose at least 2 possible, innovative solutions to solve this problem.