Lesson Plan: Galvanic Cell Exploration

FOR THE TEACHER

Summary
In this lesson, students will build their understanding of redox reactions and galvanic cells. Using both a lab activity and an animated simulation, students will investigate these types of cells (and the redox reactions that drive them) at both a macroscopic and particle-level to connect how particle-level interactions can explain macroscopic observations.

Grade Level
High School (AP level)

AP Chemistry Curriculum Framework
This lab activity supports the following units, topics, and learning objectives:

- **Unit 4: Chemical Reactions**
  - **Topic 4.2:** Net Ionic Equations
    - **TRA-1.B:** Represent changes in matter with a balanced chemical or net ionic equation: a. For physical changes. b. For given information about the identity of the reactants and/or product. c. For ions in a given chemical reaction.
  - **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.

- **Unit 9: Applications of Thermodynamics**
  - **Topic 9.7:** Galvanic (Voltaic) and Electrolytic Cells
    - **ENE-6.A:** Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.

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

- **Scientific and Engineering Practices:**
  - Developing and Using Models
  - Analyzing and Interpreting Data
  - Constructing Explanations and Designing Solutions

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

- Describe the redox reaction occurring in a galvanic cell using equations.
- Depict what is occurring in a galvanic cell with a labeled diagram.
- Predict how a cell will macroscopically change over time (where mass is lost, gained etc.) based on understanding of the cell at the particle-level.
- Apply their knowledge to novel cells to explain the underlying redox reaction using all forms listed above (equations, diagrams and predictions of how the cell macroscopically changes over time).
Chemistry Topics
This lesson supports students’ understanding of
- Electrochemistry
- Redox reactions
- Galvanic Cells

Time
Teacher Preparation: 30 minutes (Primarily to make solutions and to prepare metal pieces for the lab activity)

Lesson:
- Warm-up: 5-10 minutes
- Activity 1: metal reactivity lab introduction: 5-10 minutes
- Activity 1: metal reactivity lab data collection: 15 minutes
- Activity 1: metal reactivity post lab discussion: 15 minutes
- Activity 2: Galvanic cell simulation introduction: 15 minutes
- Activity 2: Galvanic cell simulation activity: 25-30 minutes
- Activity 2: Galvanic cell simulation post activity discussion: 10 minutes
- Application activity: 15-20 minutes

Materials
- Activity 1: Metal Reactivity lab (per group)
  - One Well plate that contains at least 4 x 4 wells to test the various metal/metal solution combinations
  *Note: Six test tubes and a test tube rack can also be used if well plates are not available
  - 2-3 Small dropper bottles of each of the following solutions: 1.0 M CuSO₄, 1.0 M AgNO₃, 1.0 M ZnSO₄
  (Only 1 dropper bottle of each per group if students are not rotating)
  - Two 1 cm samples of each metal (copper, silver and zinc). See Teacher notes for more details
- Activity 2: Galvanic Cell simulation
  - Computer (one per group)
  - Internet access
- Warm-Up PPT Presentation (available for download)
- Activity 1: Metal Lab PPT (available for download)
- Activity 2: Galvanic Cell PPT (available for download)

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
General Notes:
- An answer key for any analysis or reflection questions as well as PowerPoint slides to guide direct instruction and warm-up questions are included.
- Prior to this activity, students should have been exposed to the basics of redox reactions (including oxidation numbers and how to balanced redox equations).
Warm Up:
- Students will begin the lesson by individually working the provided problem. This problem can be shown on a projection screen or white board (Warm up PowerPoint slide with answers included in slide notes) or given as a hard copy or written on the board. This can occur as the teacher is getting things ready, taking role etc.
- The goal of this warm-up problem is to activate their prior knowledge of redox reactions and how to identify what is being reduced and what is being oxidized.
- After individual work, students can discuss their answers with a neighbor to check their understanding.
- (Optional) The teacher can collect the warm-up problems as a check of understanding or can ask for volunteers to share their answers. The entire warm-up, however, is intended to take no longer than (5-10 minutes).

Activity 1: Metal Reactivity Lab Introduction
- The teacher can use the provided Metal lab PowerPoint to lead a discussion setting up the metal reactivity lab activity. This is intended to build on first year chemistry explorations of single-replacement reactions that used a reactivity series to predict if the reaction will occur. The goal is to setup that now students will explore the rationale behind these series. If this was not the way the material was taught, the last slide can be omitted.
- The Metal lab PowerPoint includes animations. In presentation mode, each new piece of information is added with a mouse click so instead of just presenting to students, the teacher can use it to scaffold a discussion where he/she is asking students guiding questions [for example what would the reaction be if Cu (s) reacts with PbCl2 (aq)] and then revealing the information.
- The pre-activity discussion uses slides #1-3 of the provided Metal lab PowerPoint.

Activity 1: Metal Reactivity mini-lab
- The goal of this activity is not to do an extensive metal reactivity lab (for example the AACT lab: Investigating the Reactivity Series of Metals) but rather to have some macroscopic observations to link to the upcoming galvanic cell simulation work. It is assumed that students already have had some experience with the reactivity series.
- This activity is intended to be done in pairs but can be done in larger groups if needed.
- Each student group will test a total of six metal/aqueous metal solution combinations using a well plate and record if a reaction does or does not occur in their lab notebook (or other data gathering method preferred by the teacher). See included documents for expected results.
- The material list is designed for each lab table to be used as a different station with a different solution. Groups will test the solution with each metal and then rotate to the other two stations and repeat the process for those solutions. If desired, the teacher can provide all three solutions for each lab table so students do not move.
- Copper sheet or copper wire may be used and cut into 1cm pieces. Pieces of zinc foil or zinc sheet may be used and cut into 1 cm pieces. Silver wire may be used and cut into 1 cm pieces. (If needed silver wire can be ordered online from Amazon.com).
- All metals can be rubbed with steel wool prior to cutting to increase reactivity (if needed).
- Chlorides or nitrates may be used in place of the sulfates listed.
- If quantities larger than a few drops are used, a waste container should be provided for each station so that the waste can be collected and disposed of by the teacher (instead of washing it down the sink).
- While the students are working on the activity, the teacher can circulate and provide individual support (as needed).
- The student materials provide a template for the students’ data table. If desired, this can be omitted and students can be asked to generate the table independently to practice their ability to construct useful data tables.
• (Optional) If time is an issue, the teacher can have the metals pre-added to the well plates so students only need to add the solutions and observe.

Activity 1: Metal Reactivity mini-lab Post lab Discussion
• The goal of this discussion is to develop a rule so students can predict the reaction of various metals/metal ion combinations when they are used in a galvanic cell.
• The teacher can use the provided Metal lab PowerPoint to guide the discussion or they can guide the discussion without it. The goal is for students to realize the following:
  o The more positive the reduction potential for the cation, the more favorable for that cation to be reduced to the neutral metal.
  o The more negative the reduction potential for the cation, the more favorable for the neutral metal to be oxidized to the cation.
  o For a single-replacement reaction that occurs, the metal with a more positive reduction potential (more easily reduced) will be the species in solution and the metal with a more negative reduction potential (more easily oxidized) will be the species as a solid metal. This is setting up how to recognize the anode and cathode in a galvanic cell.
• The post lab discussion uses slides #4-9 of the provided Metal lab PowerPoint.
• The end of the metal reactivity lab post lab discussion is a good break point. The entire warm-up and activity 1 should be able to be completed in a 40-45 minute class period.

Activity 2: Galvanic Cell Simulation Introduction
• The teacher can use the provided Galvanic Cell PowerPoint to lead a discussion introducing galvanic cells and the cell simulation activity. This is intended as a first introduction to galvanic cells and how they utilize redox reactions. No prior experience is assumed. If students are familiar with galvanic cells this introduction can be shortened as needed.
• The Galvanic Cell PowerPoint includes animations. In presentation mode each new piece of information is added with a mouse click so instead of just presenting to students, the teacher can use it to scaffold a discussion where he/she is asking students guiding questions [for example which species would be reduced and which would be oxidized] and then revealing the information.
• The pre-activity discussion uses slides #1-8 of the provided Galvanic Cell PowerPoint.

Activity 2: Galvanic Cell Simulation
• The simulation can be found here. Flash player must be installed.
• Care must be taken to set up each cell combination with the first metal shown using the electrode on the left and the second metal shown using the electrode on the right. This note is included in the student document.
• For the teacher but not to be shared with students: Setting up the cell in this manner makes the species being reduced on the right-hand side and the species being oxidized on the left hand side so the electrons flow from left to right. Failure to do this will result in a negative cell potential being shown on the voltmeter, which may be confusing to students.
• It is included in the student notes but to close the tabs, you need to click on them and to reset the simulation you need to click on the on/off switch of the voltmeter.
• Students should work in groups of 2-3 for this activity.
• While the students are working on the activity, the teacher can circulate and provide individual support (as needed).
• The galvanic cell simulation introduction and simulation activity (minus the post-lab discussion) should be able to be completed in a 45-minute period. Students who work at a slower pace may need to do the analysis piece at home instead of during class time.
Activity 2: Galvanic Cell Simulation Post Activity Discussion

- The goal of this discussion is to recap and reinforce what students learned during the simulation.
- The teacher can use the provided Galvanic Cell PowerPoint to guide the discussion or they can guide the discussion without it. The goal is to reinforce student understanding of the following:
  - How electrons flow in a galvanic cell.
  - The reactions that occur at the cathode and anode of the cell.
  - How the metal pieces that are part of the cathode and anode change on both a particle and macroscopic level as the redox reaction proceeds.
  - How the ions in the salt bridge move as the redox reaction proceeds.
- The post lab discussion uses slides #9-13 of the provided Galvanic Cell PowerPoint.
- If the Galvanic Cell PowerPoint is used, the intention is for the teacher to review how the cells function (slides #9-10) then project slide #11 and give students an opportunity to work either in small groups or independently for 5-10 minutes to accomplish the stated tasks for one of the cells they examined in the simulation.
- After independent/group work, the teacher can use slides #12-13 to guide students to share their responses.

Application Questions Activity/Assessment:

- This activity/assessment should be completed after the post Galvanic Cell simulation discussion.
- The goal of this part of the lesson is to assess student understanding by having students analyze a novel cell and describe in using a variety of forms (e.g. diagram, equation, prediction of macroscopic changes, etc.).
- **NOTE:** If desired, the teacher can change the metal/metals solutions that are used. This may be warranted if the teacher elects to have students actually build the cell (see extension activity below) and wants to use materials that he/she has easy access to.
- This task can be given as a homework assignment or completed as an in-class activity as desired by the teacher. It can be graded or not based on teacher preference.
- The task can be assigned to be completed in small groups (2-3 students) or as individuals as preferred by the teacher.
- **Extension activity:** Students can build the cell and observe if their predictions (cell potential, electrode that gains/loses mass) are correct.
FOR THE STUDENT

Lesson

Activity I: Mini Lab Exploring Metal Reactivity

Background
In this lab we are going to explore the reactivity of different metals in single-replacement reactions by mixing various metal and aqueous metal solutions. Particular attention will be paid to which combinations will produce a reaction where the solid metal is oxidized and reduces the solution metal cation into its neutral, solid form.

Objective
The objective of this lab is to explore the reactivity of silver, zinc and copper to determine their relative reactivity in single replacement reactions. The goal is to discover the relative ease of oxidation of the three metals in their solid, neutral form and the relative ease of reduction of the three metals in their cation form.

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow the teacher’s instructions for cleanup of materials and disposal of chemicals.

Procedure
1. Add a 1 cm piece of each metal (Ag, Zn, and Cu) to appropriate cell of the well plate that matches the data table shown below.
2. Add 2-3 drops of the solution at your station to the appropriate row in your well plate
   a. If AgNO₃ (aq) solution (source of Ag⁺) add to each metal in the first row of your well plate
   b. If ZnSO₄ (aq) solution (source of Zn²⁺) add to each metal in the second row of your well plate
   c. If CuSO₄ (aq) solution (source of Cu²⁺) add to each metal in the third row of your well plate

   CAUTION: For each test be careful not to let the dropper you are using to add each aqueous solution touch the reaction solution or you will contaminate it for the next group!
3. Record if a reaction occurs by either writing “Yes” or “No Reaction” in the appropriate location in the table.
4. When prompted by your teacher, move to the next station and repeat steps 1-3 for the solution at that station.
5. When prompted by your teacher, move to the next station and repeat steps 1-3 for the solution at that station.
6. Clean-up:
   a. When you have completed all of the tests, remove any remaining metal pieces from your well plate and put them in the trash.
   b. Gently wash the contents of your well plate down the sink drain.
   c. Rinse and wash your well plate.
   d. Wash your hands.
Data
Copy the following table into your lab notebook. You will use it to record your observations during the lab.

<table>
<thead>
<tr>
<th>Metal Reactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Ag (s)</td>
</tr>
<tr>
<td>Zn (s)</td>
</tr>
<tr>
<td>Cu (s)</td>
</tr>
<tr>
<td>Ag^+ (aq)</td>
</tr>
<tr>
<td>Zn^{+2} (aq)</td>
</tr>
<tr>
<td>Cu^{+2} (aq)</td>
</tr>
</tbody>
</table>

Analysis
1. Based on your observations, rank the three metals in order of reactivity from most easily oxidized to least easily oxidized.
2. Based on your results, rank the three metal cations in order of ease of reduction from most easily reduced to least easily reduced.
3. After each group has completed the activity, we will discuss how we can predict ease of oxidation/reduction for a particular metal.
Activity II: Galvanic Cell Simulation Activity

Background
In this activity we are going to explore how redox reactions can power galvanic cells. You will make predictions about how the cells will run then test your predictions with the simulation. In addition, you will explore the redox reactions at a particle-level and investigate how those changes are affecting the macroscopic characteristics of the cells.

Objective
The objective of this activity is to test your knowledge of the redox reactions that power galvanic cells and to understand how these cells change in both a macroscopic and particle level as the redox reactions occur.

Procedure
1. Open the galvanic cell simulation link (http://pages.uoregon.edu/tgreenbo/voltaicCellEMF.html).
2. Move your mouse over the E of metals button in the lower left-hand side of the simulation (the reduction potential values should now be visible).
3. Using the reduction potential values, discuss with your partner the following for the cell made by the combination of: Ag/Ag⁺ (aq) with Zn/Zn²⁺ (aq)
   a. Which metal will be the anode?
   b. Which metal will be the cathode?
   c. Which way the electrons will flow?
   d. Which way the cation and the anion of the salt bridge will flow.
   e. What the cell potential is.
4. As you reach consensus for each combination, record your predictions in the data table. Make sure you also leave room to add the actual results.
5. Repeat steps 3 and 4 for the following cells:
   a. Ag/Ag⁺ (aq) with Cu/Cu²⁺ (aq)
   b. Cu/Cu²⁺ (aq) with Zn/Zn²⁺ (aq)
6. Follow the instructions in the simulation to build the Ag/Ag⁺ (aq) with Zn/Zn²⁺ (aq) cell and to test it.
   NOTES:
   - Use the first metal shown to build the electrode on the left hand side of the simulation and the second metal shown to build the electrode on the right hand side of the simulation.
   - Use standard conditions of 1M solutions
   - You can close a tab by clicking on it
   - You need to click on the switch to start the simulation.
   - You need to click the switch a second time to reset the simulation.
7. For each prediction, note if your prediction was correct
   a. If your prediction for the cell was correct, put a check next to it.
   b. If your prediction for a cell was incorrect, add the correct information.
8. Once the simulation has finished, examine what is happening at the anode and the cathode by clicking the “molecular level reaction” button for each one.
9. Repeat for the other two cell combinations.
10. (Optional) If you are still uncertain about what is happening at the particle level, you can also watch the following animations for what is occurring at the anode (https://vimeo.com/220550690) and the cathode (https://vimeo.com/220550267) of a galvanic cell,
## Data

<table>
<thead>
<tr>
<th>Cell combination</th>
<th>Anode</th>
<th>Cathode</th>
<th>Direction of electron flow</th>
<th>Direction of salt bridge cation flow</th>
<th>Direction of salt bridge anion flow</th>
<th>Cell potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag/Ag⁺ (aq) with Zn/Zn⁺² (aq)</td>
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<tr>
<td>Ag/Ag⁺ (aq) with Cu/Cu⁺² (aq)</td>
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<tr>
<td>Cu/Cu⁺² (aq) with Zn/Zn⁺² (aq)</td>
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## Analysis

Complete the following for each cell you examined

1. Write the overall balanced net ionic equation for the redox reaction
2. Write the cell line notation for the cell
3. A student was going to build the silver and zinc cell that you investigated above, but had silver acetate not silver nitrate. Would this change affect the cell potential? Explain your response.

**When you are done, please let your teacher know. After each group has completed the simulation, we will discuss how to represent galvanic cells using equations and diagrams.**
Representing Galvanic Cells: Application Questions

Background
You will test your understanding of galvanic cells and the redox reactions that they involve by analyzing a novel cell and describing in a variety of forms (e.g. diagram, equation, prediction of macroscopic changes, etc.)

Tasks:
1. Sketch a galvanic cell made by the following:
   Ni (s) electrode in 1.0 M Ni^{+2} (aq)
   Ag (s) electrode in 1.0 M Ag^{+} (aq)

   NOTE: Your sketch should include the following pieces of information:
   a. Cell potential
   b. Direction of electron flow
   c. Anode and cathode labels
   d. Direction of salt bridge anion flow
   e. Direction of salt bridge cation flow

2. Write the balanced reaction for this cell (assume it is in a neutral solution).
3. Write the cell line notation for this cell.
4. Predict the weight (lighter, heavier, or the same) of the Ni (s) and Ag(s) metal strips after the cell has been running for a period of time.
5. Explain your thinking for each one. If it is heavier, what has been added? From where? By what process? If it is lighter, what has been removed? By what process?
6. Predict the concentration (higher, lower or the same) of the Ni^{+2} (aq) and Ag^{+} (aq) solutions after the cell has been running for a period of time.
7. Explain your thinking for each one. If it is more concentrated, how did this happen? If it is more dilute, how did this happen?