Lab: Inquiry Redox Investigation

FOR THE TEACHER

Summary
In this lab, students perform a simple redox reaction using an iron nail and copper(II) chloride solution. They will consider both quantitative and qualitative data collected during the reaction in order to attempt to explain what happened. Students will also create particle diagrams and determine mole ratios of various species in the reaction.

Grade Level
High School

Objectives
By the end of this lab, students should be able to
- Explain the process of gaining and losing electrons.
- Define oxidation and reduction.
- Justify that a reaction is an oxidation-reduction reaction in terms of electron transfer.
- Connect the coefficients of a balanced chemical equation to the mole ratio of reacting species.
- Draw particle diagrams of a redox reaction.

Chemistry Topics
This lab supports students’ understanding of
- Chemical Reactions
- Classification of Reactions
- Balancing Equations
- Oxidation-Reduction Reactions
- Electron transfer
- Atoms and Ions
- Solutions
- Net Ionic Equation
- Stoichiometry
- Mole Ratio

Time
Teacher Preparation: 5-10 minutes
Lesson: Two-three 50 minute class periods

Materials (per lab group)
- 100 mL beaker (2)
- 3” Iron Nail (Flinn Reference No. I0032)
- Approximately 90 mL of 0.5 M CuCl₂ Solution (concentration can vary)
- 25ml of 1 M HCl solution
- Scale
- Drying oven (optional)

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.
• Solid reaction products can be disposed of in the trash and all solutions can be poured down the sink.

Teacher Notes
• The Reaction: The reaction that occurs in an oxidation-reduction reaction between iron and copper(II). The iron is oxidized, transferring electrons to copper(II) ions that are reduced. As this occurs, red copper metal is seen forming and the solution loses its characteristic blue color as the copper(II) ions leave the solution.
  o Net-Ionic Equation: Fe(s) + Cu^{2+}(aq) → Fe^{2+}(aq) + Cu(s)
  o Oxidation Half-Reaction: Fe(s) → Fe^{2+}(aq) + 2e^-
  o Reduction Half-Reaction: Cu^{2+}(aq) + 2e^- → Cu(s)

• Data Collection: The lab consistently produced a 1:1 mole ratio of reacting species, evidence for the oxidation of iron metal to form iron(II), as opposed to iron(III). For improved data analysis, collect the class mass data on the board or in a spreadsheet and keep it from year to year. This way, the average reacting mole ratio will be easier for students to observe as 1:1.
• Sometimes, a yellow-ish layer will form on top of the solution. This is likely due to a coating on the nail. This can be reduced by wiping the nails down beforehand. It should not affect results.
• Timing: This lab occurs over several days (50 minute class periods), but note that the first-day setup can be completed rather quickly by students. Additionally, once students have observed the formation of copper metal on the nail (it happens quickly) they can begin to think about what is occurring qualitatively as a homework assignment, reducing the amount of time spent in class. If you teach on a block schedule, the days will have to be modified slightly.
• Do not try to dry the solid copper in one class period, leave it to dry in the oven at a low temperature for some time to ensure it is dry. You could leave them to dry in open air if necessary. If you use a drying oven, watch the samples carefully and keep at a low temperature or the copper will oxidize. You will know if this happens if the solid turns green.
• Students may think that the red solid produced is rust. Be prepared for this. One way is to have them observe the formation of copper at another time earlier in the curriculum. A common beginning of the year lab is qualitatively observing the reaction of aluminum with copper(II) chloride.
• You could alternatively lead them through the logic that since rust is Fe_2O_3 (they probably do not know this) and rusting is a very slow process involving iron reacting with atmospheric oxygen, that it does not make sense that dipping the iron in solution (not in contact with air) could cause the reaction to happen.
• The biggest way to differentiate the post-lab is to vary the amount of information you give to your students and how much you direct the discussion.
• For a pre-lab, you could have students determine what data to collect, how to organize the data, and even come up with a procedure with teacher guidance as to the objectives of the lab.
• Once students identify that electron transfer is occurring, challenge them to represent this in an equation. They will likely produce something akin to: Fe(s) – 2 electrons → Fe^{2+}. This opens the door for a discussion about how we don’t use subtraction signs in reactions and how to represent electrons in a half-reaction equation.
• The beakers are notoriously hard to clean after this lab. I recommend using old beakers and committing them to use for this lab each year. To try and avoid this, the teacher can wash the beakers to the best of your ability and then soak them in concentrated nitric acid in a fume hood.
overnight to try to oxidize the remaining copper. Use caution when handling concentrated nitric acid: wear gloves, apron, and goggles at all times and dispense only in a fume hood. The reaction with copper produces toxic nitrogen dioxide gas.

- Analysis questions are optional. Calculations should be given to students after a class discussion about the reaction.
- For a complete look in to how this lab fits in to the curriculum of the author, please refer to the associated article, published in the March 2018 issue of Chemistry Solutions.

FOR THE STUDENT
Lesson
Lab: The Iron Nail
Background
To begin our study of chemical reactions, you will observe the chemical reaction that occurs when an iron nail is placed in a copper(II) chloride solution.

Objective
You will be able to propose an explanation to support your observation for what is occurring at the atomic level of matter when an iron nail is placed in a copper(II) chloride solution.

Materials
- 100 mL beaker (2)
- 3” Iron Nail
- About 90 mL of CuCl₂ Solution, enough to almost cover the nail.
- 25ml of 1M HCl(aq) solution
- Scale

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Solid reaction products can be disposed of in the trash and all solutions can be poured down the sink.

Procedure
Day 1:
1. Measure the mass of a 100ml beaker (it should be large enough to support your iron nail). Label with your name(s) using label tape. Record mass in the data table provided.
2. Measure the mass of an iron nail. Record mass in the data table provided.
3. Add about 90ml of copper(II) chloride solution to the beaker.
4. Place the nail in the copper(II) chloride solution. Add additional solution to almost completely cover the nail.
5. After a few seconds, remove the nail and observe the reaction that has occurred; record your observations.
6. Place the nail back in the solution and put the labeled beaker in the designated area until the next class.

Day 2:
1. Remove the nail from the solution. Rinse or scrape any remaining red solid from the nail in to the solution. Place the nail in a labeled small beaker. Note the appearance
of the nail. Place this beaker in the drying oven.
2. Decant solution from the original beaker.
3. Rinse the red solid with about 25 mL of distilled water from a wash bottle. Decant the water. Try to lose as little of the solid as possible when you decant. Repeat one more time.
4. Rinse the solid with about 25 mL of 1 M HCl. Decant.
5. Rinse one last time with distilled water. Decant.
6. Place the labeled beaker containing the red solid in the drying oven and remove your dried nail.
7. Measure the mass of the dry nails, and then discard the nails in the trash.

**Day 3:**
1. Measure the mass the beaker containing the dried red solid. Discard the solid in the waste beaker. Wash your beaker and let dry.

**Data**

<table>
<thead>
<tr>
<th>Quantitative Data</th>
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<tbody>
<tr>
<td>Mass nail before reaction (g)</td>
</tr>
<tr>
<td>Mass of beaker (g)</td>
</tr>
<tr>
<td>Mass nail after reaction (g)</td>
</tr>
<tr>
<td>Mass beaker + dry solid (g)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qualitative Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1 Observations</td>
</tr>
<tr>
<td>Day 2 Observations</td>
</tr>
<tr>
<td>Day 3 Observations</td>
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</tbody>
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**Analysis**
In preparation for a class discussion about the lab, consider the following questions.
1. Why is water able to solvate ions, but not neutral metal atoms?
2. What is the identity of the red solid? Where did the red solid come from?
3. Why did the color of the solution change from blue to clear?
4. Why did the mass of the iron decrease? Where did the iron atoms go?
5. In your group, prepare a particle diagram of what you think occurred in the reaction. You may also include chemical equations and written explanations. Your group will present your diagrams using whiteboards in the next class session.

**Calculations**
1. Determine the mass of copper metal produced during the reaction.
2. Determine the mass of iron consumed during the reaction.
3. Calculate the number of moles of copper metal produced and number of moles of iron consumed in the reaction.
4. Obtain the class average for the moles of copper metal produced and the moles of iron consumed from the teacher.
5. Determine the ratio of moles of copper to moles of iron using the class average. Express this ratio as an integer. Since the data is “raw” and subject to error, you may have to round your calculated ratio to the nearest integer.
6. Look at the balanced chemical equation for the reaction. Explain why the ratio in the equation is equivalent to the mole ratio calculated in #5.