Reactivity of Magnesium Metal for Biodegradable Medical Implants

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Abstract:
The main goal of this inquiry-based research experiment is to help develop lessons that support critical thinking and scientific processing skills by assigning students to design, collect, and process data and to provide a conclusion and evaluation of their investigations of research questions.

The objective of this experiment is to measure the corrosion rate of specific metals such as: Mg, Al, Cu, Fe, and Zn that are available in high school chemistry classrooms and that are used in a real–world application where they are subjected to different factors.

This title, which is aligned with Goal 5.06 of North Carolina's Curriculum of Chemistry, gives our students a clear understanding of and connection to learning the concepts of assessing the factors that affect the rates of chemical reactions: The nature of the reactants, temperature, concentration, surface area, and catalysts in a real-world application, while scientists are at work.

In addition, the activities related to this topic help the students to review the scientific methods and engage the students in science inquiry which will help them to develop the ability necessary to perform and understand scientific inquiry aligned with Competency Goal of the National Science Education Standards.

Objectives:
The student will be able to:

- Discuss the impact corrosion may have in metallic biomaterials.
- Observe and understand the changes that occur to metals when submerged in an aqueous solution such as: De-Ionized water (DI), salt solutions (NaCl), and simulated body fluid (SBF).
- Investigate the factors that affect corrosion**.**
- Identify the elements oxidized and reduced.
- Write simple half reactions.
- Compare and contrast the effects of corrosion on various types of metals.
- Assess the practical applications of oxidation and reduction reactions.

MatEd Core Competencies Addressed (most important in bold)

0B Prepare Tests and Analyze Data
5A Apply Safe and Environmentally Appropriate Methods to Chemical Handling
5B Demonstrate Knowledge of Chemistry Fundamentals
7KCompare Thermal, Physical and Other Properties of Materials
8A Demonstrate the Execution of Materials Experiments
9C Identify Types, Properties and Processing of Aluminum and Aluminum Alloys
9D Discuss Types and Advantages of Copper and Its Alloys
9E Explain Common Uses for Zinc and Its Alloys
9F Identify Properties and Uses of Magnesium and Its Alloys

Key Words: Alloys, metallic corrosion, reaction rates, oxidation- reduction

Type of Module: Demonstration, inquiry investigation, class experiment with observation, and measurements over a period of time

Time Required:
10 minutes to assess and activate students' prior knowledge- "KWL"
15 minutes for the demonstration
Two class periods to design their investigation
One class period to set up
5 – 14 or longer days for observation and recording data

Grade Levels:
Grades 9 through 12

Table of Contents:

Equipment and Supplies Needed:
The following materials need to be available in the lab for the students to use**.** Some of these materials (specially the metals) are available at a hardware store or on eBay.

- Mg metal rod
- Electronic balance
- DI water, NaCl, and SBF
- 250 ml Beakers
- 400 ml Beakers
- Graduated cylinder
- 4L Erlenmeyer flask
- Stirring rod
- Hot plate
- Thermometer
- P^H meter
- Samples of Mg, Cu, Al, Zn, and Fe metals
- Ruler
- Electric tape
- Scissors
- Sandpaper
- Dental floss
- Popsicle sticks
- Crazy Glue sticks
- Al foil
- Gloves
- Isopropyl (rubbing) alcohol

Instructor background and notes:
Most metals often react with atmospheric oxygen to produce chemically stable oxide and hydroxide compounds. This electrochemical process, known as corrosion, is characterized by a flow of electric current. Electrons from a region of chemical oxidation (anode) are transferred to regions of chemical reduction (cathode).

The most common example is the rusting of iron. When iron is exposed to oxygen and water, iron oxide or rust (FeO, or Fe_2O_3) will form.

Corrosion is the gradual destruction of material, usually metals, by chemical reaction within its environment. http://en.wikipedia.org/wiki/Corrosion

The study of corrosion is very important because it prevents the spending of billions of dollars each year in replacement and maintenance costs of medical equipment, water tanks and pipes, bridges, and transportation materials such as cars, ships, and airplanes. The outcome will be great for economic growth and gives better and longer lives to humans in our society. In this investigation, the focus will be to understand the chemistry behind the study of potential implants in the human body.

Magnesium (Mg) alloys have drawn interest over the past years due to their potential as implant materials. Conceptually, an implant constructed of magnesium can be used to help the body heal. Once the body has healed, the implant can dissolve away slowly, since the body has metabolic pathways available to eliminate the magnesium. Careful design of the magnesium alloy will allow for implants that maintain structural integrity for a long enough time to allow healing to occur (such as broken bone repair), then dissolve away at a controlled rate so that local toxicity behavior is under control. Replacing titanium (Ti) type implants with magnesium could reduce the amount of secondary procedures and associated complications to remove the titanium implant when it is no longer needed.

Corrosion is the wearing away of metals due to a chemical reaction. The corrosion of a magnesium alloy begins with the transfer of electrons from magnesium to hydroxide (from the anode to cathode). The rate of corrosion is affected by water and accelerated by electrolytes. Chemical reactions where electrons are transferred between molecules are called oxidation/reduction (Redox).
Magnesium reacts slowly with water vapor to form magnesium hydroxide and hydrogen gas:

$$Mg\ (s) + 2H_2O(g) \rightarrow Mg(OH)_2(aq) + H_2(g) \qquad (1)$$

In this experiment, students will investigate the effects of temperature, P^H, particle size, types of metals, concentration or aqueous solutions, and types of aqueous solution materials on the rate of corrosion of specific metals. NOTE: Students can set up their own time, but it usually takes 5−14 days of immersion in the solution to yield a useful result. Students must also understand the difference between independent, dependent, and control variables before they proceed to design their own experiment. Please see the detailed instructions below regarding the germane lesson plans.

Pre-Lab Calculation

Table 1.Students will need to calculate the molarity of the following compounds:

• Compound Composition of SBF (g/L)			
Formula	**Name**	**Concentration (g/L)**	**Molarity**
NaCl	Sodium Chloride	8.00	
KCl	Potassium Chloride	0.40	
$CaCl_2$	Calcium Chloride	0.14	
$NaHCO_3$	Sodium Bicarbonate	0.35	
MgSO4·7H2O	Magnesium Sulfate Heptahydrate	0.2	
Na2HPO4·7H2O	Disodium Phosphate Heptahydrate	0.06	
$KHPO_4$	Potassium Hydrogen Phosphate	0.09	
$C_6H_{12}O_6$	Glucose	1.00	

Experimental Process:

Table 2. Experimental Procedure for Students

Bell Ringer	Pose open-ended broad questions, which are the focus of the lesson - Essential Questions (EQs).	1. Students will copy the following **essential questions** for the lesson: A. What is corrosion and what causes it? B. How do you determine which species is oxidized or reduced in a reaction? C. How can you determine what materials can react with metals, causing the metals to corrode? D. How do you think you could slow down the oxidation process involved in the corrosion of some metallic materials? E. How do you design, conduct, and analyze to investigate some of the factors that affect corrosion rates?
Engage	Assess and activate students' prior knowledge- KWL **K- What I know** **W- What I want to know?** **L- What I have learned** Teacher Input: Motivate and link to the concept to be learned- Anticipatory Set – using the guided study mini-lab. Procedures will be given to complete the corrosion of the iron -mini lab.	2. Students will observe a car left for a long time outside of a Junkyard, and will be asked to write what they see and what they know about the picture in their KWL handout chart (Page 13). 3. Students will observe and experiment with the corrosion of iron. Specifically, they will observe iron tightly wrapped with copper wire and iron tightly wrapped with zinc strips immersed in three different beakers in a mixture consisting of 0.9%NaCl as a medium through which ions and electrons can move to complete the electrochemical circuit, and two indicators (hexacyanoferrate (III) ion and phenolphthalein) used to signal the formation of Fe^{2+} ions (which turn blue) and OH^- ions (which turn pink) as products of the corrosion of iron.

Explore	Participate in a laboratory investigation: You just received an award for young scholarly research from the Engineering Research Center for Revolutionizing Metallic Biomaterials at North Carolina A&T State University. The research at the university is focused on studying metals as potential bio-degradable and bio-absorbable materials for medical implants to replace a diseased body part or to assist a healing process. However, the major limitation of using metals, such as Mg, Cu, and others, is their low corrosion resistance in the human body. Your research investigation will be to design an experiment to see what factors affect the reactions or corrosions of metals when they are subjected to corrosive environments.	4. Students will plan, design, conduct, analyze, and share their investigations on what factors affect the reaction rates of corrosion on selected metallic biomaterials. (Students have to come up with open ended question(s); give background information based on their observations or research; formulate hypotheses; select independent variables/dependent variables and controlled variables; determine what materials to use that are already in classroom; and write procedures before proceeding to conduct their investigations. Students, then, collect processes and present their data, write their conclusion, evaluate their procedure, and give recommendations on how they can improve their investigations.
Explain	<u>Teacher Input:</u> Teacher asks questions about what students learned from the activities and how they will connect it to the concept being learned. Teacher will also explain the process of the new knowledge of oxidation –reduction reactions and factors affecting the rate of a reaction (corrosion) of selected metallic biomaterials implants-PowerPoint notes.	5. Students will share some of their answers with the whole class by showing the steps of how they arrived at their final answers. 6. Teacher will review the process and give feedback to whole class. 7. Teacher will introduce new concepts or processes using a PowerPoint outline: How metallic biomaterials are used in real world research.

Elaborate	Independent Practice Students will gain a deeper understanding of the concepts learned using a real world application and how they can apply it to their daily lives.	8. Students will analyze the graph found on page 9 (Figure A), and answer the questions on page 10 and fill in the blank Table A on page 11. 9. Student will work on PowerPoint presentations.
Evaluate	Closure Students will be assessed on whether they mastered the objective and understand the concepts by comparing the pre-assessment and post assessment on KWL, classroom participation exercises, one-minute assessment, design lab reports, and using the following IB rubrics. http://ibchem.com/IB/ibe/criteria.htm	10. Students will share their answers to the essential questions EQ(s) found on page 6 with the whole class. 11. Refer to the KWL: Students will provide a list of what they learned from this lesson. 12. Students will turn in their analytical data.
Modification	Provide written specific instructions for the activity. Provide more challenging in-depth problems and questions as extra credit. Follow the IEP modification for students with disabilities.	
Reflection	Teacher will evaluate how many students mastered the concepts and make notes for review, adjustments, and future use.	

Further Study:

Look at Figure A, "Graph of Weight Loss (%) vs. Time (hrs)," and answer the questions in Table -1.

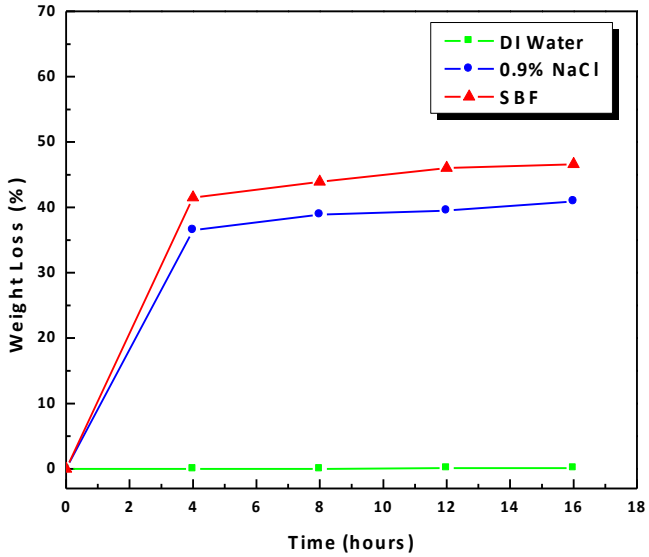

Figure A. Graph of Weigh Loss (%) vs. Time (hrs)

Figure B. Pictures of Mg Degradation

[The source of the graph on Figure A and Figure B pictures are, in part, credited to the NSF-funded Research Experience for Teachers (RET) program at NC A & T State University]

Questions

1. Look at Figure A and record the weight loss (%) of each color-coded graph.
2. Look at Figure A and record the time (hrs) of each color code.
3. What relationship do you see between the weight loss (%) and time of immersion (hrs) on the Figure-A model of each graph?
4. How do you explain the weight loss % difference between the three graphs?
5. Why do you think the Mg immersed in DI water has an almost straight-line graph?
6. What do you see happening in the graph of .9% NaCl and SBF solutions during the first four hours of reaction vs. the following 4 hours?
7. How would you explain the difference?
8. How can you describe the pictures of the metal samples on DI water, .9% NaCl, and SBF?

Table A. Experimental Table for Weight Loss Measurement

Fig.A. Graph of Weigh loss (%) VS Time (hrs).			
Graph of colors	**1. Weight loss – (%)**	**2. Time -hrs**	**3. Explain relationship of each graph**
Give a summary of the process on how the weight loss method test is done and how can the information we gain from the process help us in real-life situations.			

References

1. **What is Corrosion?**
   http://www.corrosion-doctors.org/Principles/What-is.htm

2. **How Do You Explain Corrosion?**
   http://www.corrosion-doctors.org/Principles/Theory.htm

3. **Corrosion Basics: An Introduction**
   2nd Edition, by Pierre R. Roberge

4. **Reactivity of Iron:**
   Thomas Stoebe
   University of Washington
   Seattle, WA
   http://www.materialseducation.org/educators/mated-modules/docs/Reactivity_of_Iron.pdf

5. **Fix, Heal, and Disappear: A New Approach to Using Metals in the Human Body:**
   By Barbara A. Shaw, Elizabeth Sikora, and Sanna Virtanen
   http://www.electrochem.org/dl/interface/sum/sum08/su08_p45-49.pdf

Student Evaluation Questions (Discussion or Quiz):

Students will be assessed on whether they mastered the objective and understand the concepts by comparing the pre-assessment and post-assessment on KWL, classroom participation exercises, one-minute assessment, design lab reports, and using the following IB rubrics:
http://ibchem.com/IB/ibe/criteria.htm

Instructor Evaluation Questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the demonstration/lab generate interest among the students? Explain.
4. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course Evaluation Questions (for the students):

1. Was the activity clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned

Topic: Factors Affecting Metallic Corrosion

1. Look at the attached picture of the car left outside for at a Junkyard. Observe and answer the questions on the KWL chart entitled, "What I Know."
2. After about five minutes, you will share your answers to the questions on the chart with classmates.
3. Then, you will come up with questions you have or to which you would like to know answers and write the questions in the KWL chart entitled, "What I Want to Know."
4. The final column in the KWL entitled, "What I Learned," is to be completed at the end of the lesson, which demonstrates what you have learned.

Name:

K- What I Know	W- What I Want to Know	L- What I Have Learned
1. Describe what you saw in the picture.		
2. What causes the color of the cars to change?		
3. How do you explain the chemistry behind the color change of the cars left out for a long time outside of a junkyard?		
4. How does learning about corrosion apply in real life applications?		