SAVE YOURSELF - SACRIFICIAL ANODES | EDUCATOR

Links to Next Generations Science Standards |

HS-PS1-1.
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

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.

Module Theme | Science & Engineering
Contributing Author | Cassi Weathersbee, Science Communication Fellow
Pacing | One 45-minute class period
Assessment | Student worksheet and participation in discussion
Materials/Resources |

- Glass stirrer or plastic spoon (one needed during teacher preparation)
- Needle nosed pliers (one needed during teacher preparation)
- Pair of scissors
- Microwave or hotplate
- Gloves - for handling copper scouring pad and warm glassware
- Copper acetate solution — order from chemical supply (high concentration) or make your own with the instructions included (lower concentration)
  - Distilled white vinegar (5% acidity)
  - Hydrogen peroxide (3% or higher)
  - Copper scouring pad

For each group:

- 1 wide mouth mason jar or beaker for copper acetate solution
- 2 alligator clips / leads
- 1 copper scouring pad
- 6V Lantern Battery (Can replace with several 1.5V batteries in series)
- paper towels and soap
- 1, 6 cm piece of aluminum wire (18 gauge)
- 1, 6 cm piece of galvanized steel wire (20 gauge)
- 1, 6 cm piece of aluminum wire (18 gauge) with galvanized steel wire (20 gauge) wrapped around in a tight coil near one end of the wire.

Overview

In this module, students will investigate how rates of galvanic corrosion reactions vary among different metal types with and without addition of sacrificial anodes. This is a redox reaction example. Students will learn how corrosion mitigation supports the operations of E/V *Nautilus* and the ROVs *Hercules* and *Argus*.

Objectives & Learning Outcomes

Following this activity, students will:

- understand and explain the concept of corrosion, its causes, and discuss methods used to prevent corrosion.
- understand what sacrificial anodes are and how they function.
- understand and explain why sacrificial anodes are vital to the operations of Exploration Vessel *Nautilus* and its two ROVs *Hercules* and *Argus*.

Safety

Copper acetate is poisonous. Do NOT drink the solution. Be sure to wash your hands after set-up and wipe down any surfaces that come near or into contact with your solution. Dedicate a container to it that will never be used for food. In addition, use care when handling the sharp pointed ends of the wires. The copper scouring "scrubby" material can also be sharp - you may want to use gloves while pulling this material apart.

Extensions & Adaptations

Introductory |

Chemistry of Rust Oxidation Blog & Lab http://blog.growingwithscience.com/2013/03/the-chemistry-of-rust-oxidation/

Advanced |

Research the National Association of Corrosion Engineers - an international trade agency of professionals who develop training and technologies to protect against damage to infrastructure from the many types of corrosion. Challenge students to explore industries that rely on these careers and the pathways to working in the field.

Introduction

E/V *Nautilus* has two Remotely Operated Vehicles (ROVs), *Hercules* and *Argus*, which scientists use to study deep ocean environments. Conditions for ROVs on the seafloor are harsh: cold temperatures, high pressure, and corrosive salt water. Both *Hercules* and *Argus* are made of steel which left alone will corrode in seawater and air. To reduce the amount of corrosion on the ROV frames, engineers bolt on zinc sacrificial anodes. Sacrificial anodes are a disk/block of highly electrically active metal used to donate electrons to a less-active material surface preventing corrosion, which is why the active metal is referred to as a "sacrificial" anode. Sacrificial anodes are formed from metal alloys with a more negative electrochemical potential than the metal they protect. Because the zinc disks corrode, the ROVs' steel frames are protected.

When metal come into contact with electrolytes, metal undergoes an electrochemical reaction known as galvanic corrosion. Corrosion is the process of returning a metal to its natural state as an ore and in this process, causing the metal to disintegrate and its structure to weaken. Steel immersed in seawater is one example of iron metal coming into contact with electrolytes. Metals are used in construction all around us — electrical wiring, pipelines, ships, and buildings. It is important to ensure metals last as long as they can, and one way of extending that life is corrosion protection.

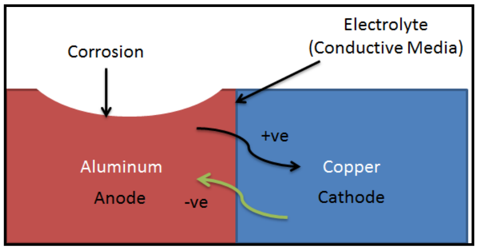
In this module, students will investigate how a sacrificial anode works by comparing the rate of corrosion on aluminum wire with and without corrosion protection. Galvanized steel wire will be coiled around aluminum wire to serve as a sacrificial anode. Galvanized steel contains zinc in its coating which is more reactive than aluminum and will corrode before the aluminum wire. Students will observe that an aluminum wire will corrode more quickly alone without galvanized steel wire wrapped around it.

Background for Educators

The four required components of a corrosion reaction are an anode, cathode, conductor path, and conducting electrolyte. The cathode is the electrode to which electrons are transferred. The anode is the electrode which donates electrons and into which current flows.

The anode is that component that is corroded. A simple method to protect a metal from corrosion is to connect that metal to a more easily corroded "sacrificial metal" to act as the anode.

Figure from Fusion Engineering and Design Journal, ITER Organization component cooling. Steven James Ployhar, et al. 2015.



Guiding Questions

1. What is corrosion? What are the components of a corrosion reaction?

   Corrosion is the process of returning a metal to its natural state as an ore and in this process, causing the metal to disintegrate and its structure to grow weak. The four required components of a corrosion reaction are an anode, cathode, conductor path, and conducting electrolyte.

2. What is the purpose of using sacrificial anodes?

   Sacrificial anodes are used to protect metal structures from corroding in the presence of an electrolyte solution.

3. How do sacrificial anodes function?

   Sacrificial anodes work by oxidizing (losing electrons) more quickly than the metal they are protecting, being consumed completely before the other metal reacts with the electrolytes.

Vocabulary

Corrosion is the process of returning a metal to its natural state as an ore and in this process, causing the metal to disintegrate and its structure to grow weak.

Anode are the electrodes from where electrons emerge and the conventional current flows into.

Cathode are the electrodes to where the electrons go and the conventional current leaves.

Electrolytes are liquids or gels that contain ions and can be decomposed by electrolysis.

Electrolysis is the chemical decomposition produced by passing an electric current through a liquid or solution containing ions.

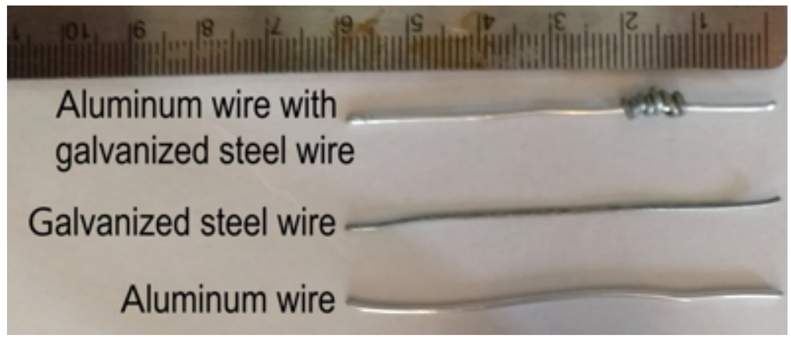
Galvanized like 'galvanized steel' refers to a thin layer of zinc coating on a metal piece.

ROV (Remotely Operated Vehicle) is a tethered underwater mobile vehicle.

Sacrificial Anodes are highly active metals used to prevent a less-active material surface from corroding. Sacrificial Anodes are created from a metal alloy with a more negative electrochemical potential than the material it will be used to protect. The sacrificial anode will be consumed instead of the metal it is protecting, which is why it is referred to as "sacrificial".

Pre-Lab Preparation

1. For each group, cut two 6 cm pieces of 18 gauge aluminum wire and two 6 cm pieces of 20 gauge galvanized steel wire. (Other gauges should also work as well.)
2. Using a pair of needle-nosed pliers, tightly wrap a piece of galvanized steel wire around one of the aluminum wires. Begin your coil of galvanized wire about 1 cm from the end of the aluminum wire. The coil should be ~1 cm wide when complete.



3. Prepare the copper acetate solution for each group using the steps below. Each group will need enough solution to fill a wide-mouth glass container/beaker at least one to two centimeters higher than the length of the wires.
   A. In the beaker add equal parts distilled white vinegar and hydrogen peroxide. Hydrogen peroxide will cause the copper (from the scrubber) to oxidize quickly which then allows the copper to react with the acetic acid rapidly.
   B. Heat the mixture in the microwave or on a hot plate until it steams gently. Heating the mixture will speed up the chemical reaction in the next step. Depending on the microwave, this will take 1:30 - 2:00 minutes. If heating the mixture on a hot plate, make sure to use a glass container and heat on low.
   C. Before continuing, wash your hands well to remove any oils from your skin. Oils will prevent the vinegar and hydrogen peroxide mixture from reacting with the copper.
   D. Stretch out the entire copper scouring pad. Pads can be unrolled once the end is untwisted. The idea is to expose as much of the copper to the vinegar-peroxide mixture as possible. The "scrubby" material can be quite sharp - you may want to put on a pair of gloves to do this.
   E. Place the copper mesh into the warm vinegar-peroxide mixture. You may need to push the copper mesh down into the solution. Use a glass stirrer or plastic spoon to gently swirl the liquid and copper in the beaker. As time passes, the mixture will become bluer and bluer. The blue color comes from the copper ions in the reaction forming copper acetate. You will also notice the scrubby mesh will lose its copper color, exposing the steel mesh. Once this occurs remove the mesh as it will begin to rust.

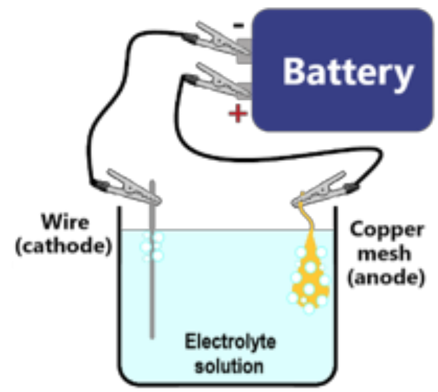
$$H_2O_2 + 2\,CH_3COOH + Cu \rightarrow C_2H_4CuO_2 + 2\,H_2O$$

Copper Acetate

Teaching Guide

Opening: Discuss what corrosion is with the class and talk about where they have seen corrosion in their everyday lives. Lead a discussion why corrosion might be a particular problem for E/V *Nautilus* and its ROVs. Ask students to think of ways they might try to reduce the amount of corrosion that takes place on expensive or sensitive equipment. Note: students may not be able to come up with any suggestions of how to prevent or reduce corrosion and that is fine. Use that opportunity to introduce the idea of sacrificial anodes.

Lab procedures:



1. Group students into groups of three to four students.
2. Review all of the safety procedures described on the student lab sheet and the guidelines used by your school and/or school district.
3. Review the procedures described on the student lab sheet before allowing the students to proceed with the lab.
4. While the students are conducting the lab the teacher should go around to the different groups answering questions and providing assistance as needed.

Possible data and observations:

1. The galvanized wire is covered in zinc. Describe any changes in the wire after being submerged in the vinegar-peroxide mixture while an electric current flowed through it.

   - The entire wire turns black, except for the part of the wire that was not submerged in the solution. The wire corroded in the solution.

2. Look carefully at the top (near the alligator clip), the middle, and the bottom of the aluminum wire. Describe any changes in the aluminum after being submerged in the vinegar-peroxide mixture while an electric current flowed through it.

   - The wire looks more corroded or rougher near the end of the wire. (Note: students may need to look very closely to observe this result.) Look for bubbles to appear at one end of the electrode.

3. Look carefully at the top (near the alligator clip), the middle, and the bottom of the aluminum wire wrapped with galvanized steel wire. Compare any corrosion of the wrapped wire to the corrosion of the aluminum only wire. Did one experience more corrosion than the other?

   - The end of the aluminum wire that was wrapped in the galvanized steel wire did not corrode as much or look as rough as the end of the aluminum wire that was not wrapped in the galvanized steel wire.

4. Look at the wire wrapped with galvanized steel wire again. Compare any corrosion of the galvanized steel wrapped wire to the straight, individual piece of galvanized steel wire. Did one experience more corrosion than the other?

   - The two pieces of galvanized steel wire should experience similar amounts of corrosion.

Teaching Guide

Answers to Student Data Analysis and Conclusion Questions:

1. Galvanic corrosion is when two different metals are in contact in the presence of an electrolyte. An electrolyte is often a liquid that contains ions. What electrolyte might the ROVs of E/V *Nautilus* come into regular contact?

    Seawater is an electrolyte because $NaCl + H_2O \rightarrow Na^+ + Cl^- + H_2O$

2. Sacrificial anodes are highly electrically active metals that are used to prevent a less active material surface from corroding losing their own mass in the process, which is why it is referred to as a "sacrificial" anode. Based on your observations, which metal acted as the “sacrificial” anode? Support your answer with your observations.

    The galvanized steel wire acted as the sacrificial anode because..

3. Look at the chart to the side. If you were going to design your own ROV and had to pick either magnesium or nickel as sacrificial anodes, which would you pick and why?

    Magnesium is more galvanically active and therefore would make a better sacrificial anodes.

4. Read the Voices in STEM section on the previous page.

    Answers will vary.

Closing:

Ask students what the purpose of sacrificial anodes is. They should be able to state that the purpose of sacrificial anodes is to protect metal structures from corroding. Lead the class in a brief discussion of where sacrificial anodes are used. This includes any location where two metals are making either direct contact or indirect contact in the presence of an electrolyte. Some examples include: hulls of ships, water heaters, water and sewer pipelines, liquid distribution systems, above-ground tanks, underground tanks, and refineries. Discuss whether or not students think the use of sacrificial anodes are a permanent solution to corrosion. Students should infer that because these anodes must be periodically inspected and replaced they are a temporary solution to corrosion.

You can also talk with the students about the importance of sacrificial anodes in the maintenance of any boat. There are three main types of sacrificial anodes, zinc, aluminum, and magnesium. When selecting a sacrificial anode it is important to consider the conditions the boat is likely to encounter. Zinc anodes offer no protection in freshwater, while aluminum offers protection in freshwater, saltwater and brackish water (to varying degrees), so manufacturers work to provide a sacrificial anode that will offer the most possible protection without knowing all the variables. If your boat is in saltwater only, take note of your location: in very warm tropic waters, aluminum anodes have a shortened useful life as the higher temperatures cause the aluminum to corrode faster than zinc. While aluminum anodes can be used in freshwater, both aluminum and zinc anodes are inferior to magnesium anodes in freshwater. Magnesium anodes offer NO protection in saltwater though – they may actually increase the rate of corrosion.

References:

- https://chem.libretexts.org/Core/Analytical_Chemistry/Electrochemistry/Exemplars/Corrosion/Sacrificial_Anode
- https://chem.libretexts.org/Core/Analytical_Chemistry/Electrochemistry/Exemplars/Corrosion/Sacrificial_Anode
- https://citimarinestore.com/citiguide/when-to-use-zinc-anodes-over-aluminum-anodes-on-a-boat/
- http://www.instructables.com/id/High-Quality-Copper-Plating/
- http://homechemistry.blogspot.com/2008/01/penny-chemistry-verdigris-and-copper.html

SAVE YOURSELF - SACRIFICIAL ANODES | STUDENT

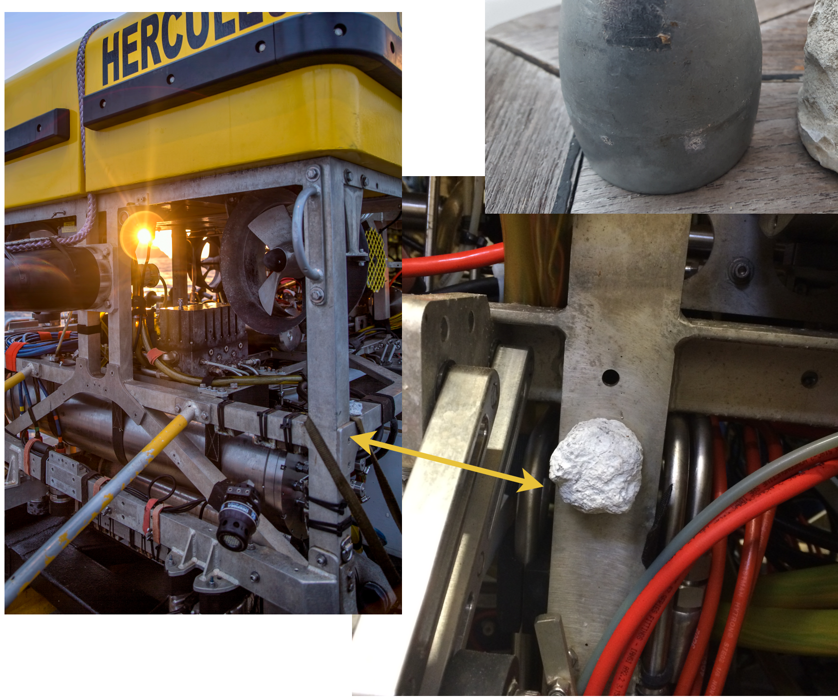
Learning Goals

- Explain the concept of corrosion, its causes, and methods used to prevent corrosion.
- Describe what sacrificial anodes are and how they function.
- Explain why sacrificial anodes are vital to the operations of E/V *Nautilus* and ROVs *Hercules* and *Argus*

Introduction Corrosion is the process of returning a metal to its natural ore state and in this process, causing the metal to grow weak and disintegrate. E/V *Nautilus* has two Remotely Operated Vehicles (ROVs), *Hercules* and *Argus*, which scientists use to study deep ocean environments. Conditions for ROVs on the seafloor are harsh: cold temperatures, high pressure, and corrosive salt water. Both ROV *Hercules* and *Argus* are made largely of steel which corrodes quickly in saltwater.

To protect the ROVs and reduce amount of corrosion, ROV engineers bolt zinc sacrificial anodes onto the frames. Sacrificial anodes are a disk/ block of highly reactive metal which corrode quickly. Because these anodes are present, the ROVs' less-reactive steel frames are protected.

Marine-grade zinc sacrificial anodes new and after eighteen-months of saltwater exposure.



One of many sacrificial anodes bolted onto ROV *Hercules*.

In this module, you will test the corrosion rate of two metal types in an experiment on aluminum wire with and without a sacrificial anode.

Helpful Resources:

Background information on corrosion reactions:

Learn the basics in 'Corrosion 101' from the National Association of Corrosion Engineers - an organization for STEM professionals who protect bridge, waterway, aerospace and manufacturing systems. https://www.nace.org/corrosion-101/

Vocabulary

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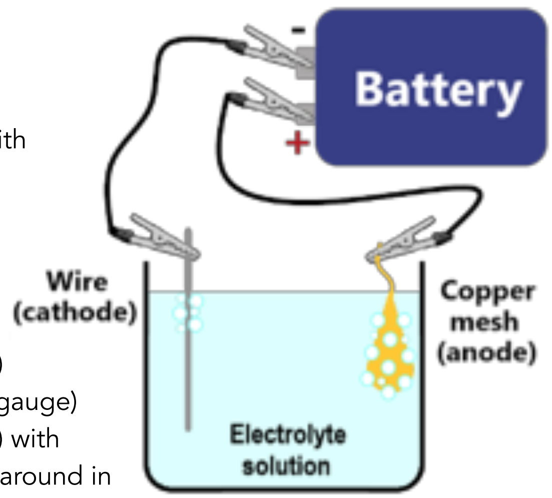
Materials

- 1 wide mouth mason jar or beaker filled with copper acetate solution
- 2 alligator clips / leads
- 6V lantern battery (or substitute 4, 1.5V batteries in series)
- paper towels and soap
- 1, 6 cm piece of aluminum wire (18 gauge)
- 1, 6 cm piece of galvanized steel wire (20 gauge)
- 1, 6 cm piece of aluminum wire (18 gauge) with galvanized steel wire (20 gauge) wrapped around in a tight coil near one end of the wire.

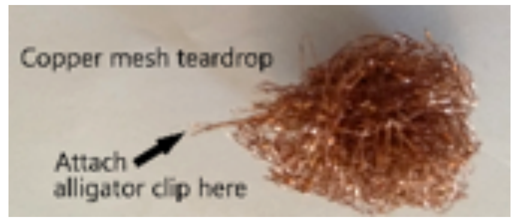


Safety Considerations

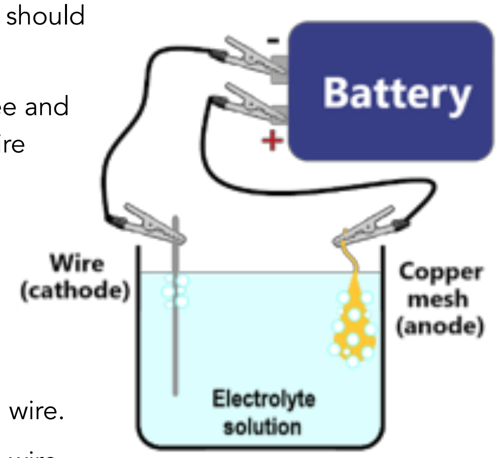
Copper acetate is poisonous. Do NOT drink the solution. Be sure to wash your hands after set-up and wipe down any surfaces that come near or into contact with your solution. Use a beaker or jar that will never be used for food. In addition, use care when handling the sharp pointed ends of the wires. The copper scouring "scrubby" material can also be sharp - you may want to use gloves while pulling this material apart.

Lab Procedure

1. Set out all materials at your lab station. Fill the beaker with warm copper acetate solution (hydrogen peroxide and vinegar) to a depth at least two cm deeper than the length of the wires.
2. Unroll and stretch out the copper scouring pad. Cut it into three equal pieces. The copper "scrubby" material can be sharp - wear a pair of gloves to do this.
3. Squeeze each copper scouring pad piece into a teardrop shape. The wide end needs to be tightly packed so that it doesn't float. The electrolysis reaction creates bubbles which can get trapped in your wire mesh. The teardrop should not be longer than the wires.
4. On the pointed end of each copper teardrop, take several wire strands and twist them into a point that can stick up and out of the copper acetate solution. Reference the picture to the side to help you.



5. Clean all three wires with soap to remove hand oils, grease, and dirt from the wire. Rinse the wire thoroughly and pat dry with a paper towel. Leave the wires on the paper towel.
6. Take one alligator lead and clip one end to twisted, narrow end of one of your copper scrubber electrodes. Connect the other alligator lead to the positive terminal on your battery. This is now your **anode**.
7. Attach the second alligator lead to the plain galvanized steel wire. Take the other end of the alligator lead and connect it to the negative terminal on your battery. This is now your **cathode**.
8. Check that the copper teardrop is attached to the positive terminal of the battery and the galvanized steel wire is connected to the negative terminal of your battery. If this is done backwards, the reaction will not work and you will contaminate your electrolyte and experiment.
9. On opposite sides of the beaker, without submerging the alligator clips, fully submerge galvanized steel wire and the copper teardrop in the copper acetate electrolyte solution. Keep the galvanized steel wire at least an inch or more away from your copper electrode. Your setup should look like the graphic.



10. Start timer for 3:30. Record your observations in the table below. After three and half minutes, remove both the copper teardrop and the galvanized steel wire from the electrolyte solution.
11. Release the copper teardrop anode from the alligator clip. Dispose of the copper anode in trash can.
12. Remove the galvanized steel wire cathode from the alligator clip. Place it on a piece of paper noting which side was attached to the alligator clip.
13. Repeat steps 6 through 12 using a new copper teardrop and the aluminum wire.
14. Repeat steps 6 through 12 using a new copper teardrop and the aluminum wire with the galvanized steel coil near one end. Make sure to connect the alligator clip to the end wire end away from the galvanized steel wire coil.

VOICES IN STEM

Bob Waters

ROV Hercules Pilot

OET Facilities Manager and ROV Engineer

Bob Waters enjoys being in the field and exploring places no one has ever seen before. His role as an ROV engineer allows him to do just that. Across his career, he has piloted DSV *Alvin*, ROV *Jason*, *DSL120* and, ROV *Doc Ricketts*. Bob began his training in the US Coast Guard where he studied electronics. He later went on to take courses at technical school in physics, calculus, electronic systems, and different engineering types. Bob encourages anyone who views themselves liking to take things apart or problem solve to consider a career as ROV engineer or pilot. Bob's advice to new engineers is to remember that the skills of piloting underwater vehicles are secondary to the skills of being able to fix them. ROV pilots work as a team to troubleshoot problems with sensors or systems on the ROVs and to create new tools when needed for an expedition.

Data Observations

1. Look carefully at the galvanized wire at the top (near the alligator clip), middle, and bottom of the wire. Describe any changes in the wire after being submerged in the vinegar-peroxide mixture.

2. Look carefully at the aluminum wire at the top (near the alligator clip), middle, and bottom of the wire. Describe any changes observed after being submerged in the vinegar-peroxide mixture.

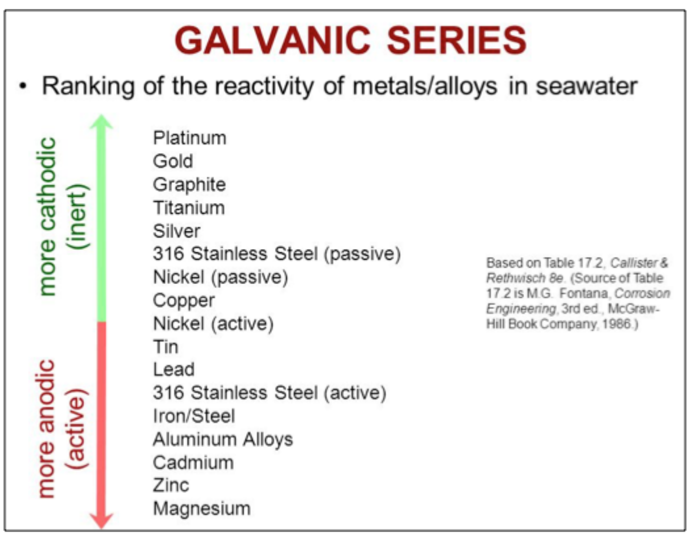
3. Look carefully at the aluminum wire wrapped with galvanized steel wire at the top (near the alligator clip), middle, and bottom. What do you observe? Compare any corrosion of this wire to the corrosion of the straight aluminum wire. Did one experience more corrosion than the other?

4. Look again at the aluminum wrapped with galvanized steel wire again. Compare any corrosion of this wire to the corrosion of the straight piece of galvanized steel wire. Did one experience more corrosion than the other?

Data Analysis and Conclusions

1. Galvanic corrosion occurs when two different metals are in contact in the presence of an electrolyte. An electrolyte is often a liquid that contains ions. What electrolyte might the ROVs of E/V *Nautilus* come into regular contact with?

2. Sacrificial anodes are highly electrically active metals that are used to prevent a less active material surface from corroding, losing mass in the process which is why it is referred to as a "sacrificial" anode. Based on your observations which metal acted as the sacrificial anode. Support your answer with your observations.



3. Look at the Galvanic Series chart. If you were going to design your own ROV and had to pick either magnesium or nickel as sacrificial anodes, which would you pick and why?

4. Read the Voices in STEM section on the previous page. What part of an ROV engineer's job would appeal to you more: designing, maintaining, and problem-solving mechanical and electrical systems on an ROV or piloting the vehicle? Both can be rewarding and challenging. Explain your choice.