Ocean Exploration & Research

Galvanic vs. *Titanic*?

Image captions/credits on Page 2.

lesson plan

Note: This lesson was originally created as part of the Ocean Explorer 2004 Return to Titanic Expedition. Because the original version involved the use of hydrochloric acid, the Learning Procedure has been revised so that it may be completed entirely by students.

Focus

Galvanic exchange and deterioration of the *Titanic*

Grade Level

7 - 8 (Physical Science)

Focus Question

How does the variety of metals used in constructing the *Titanic* contribute to deterioration of the shipwreck?

Learning Objectives

- Students will be able to describe galvanic exchange and explain how it contributes to deterioration of the *Titanic*.
- Given two dissimilar metals, students will be able to make measurements to determine their relative positions in an electromotive series.
- Given two dissimilar metals and information on their position in an electromotive series, students will be able to predict which of the metals will deteriorate if they are placed in a salt solution.
- Students will be able to list two other processes that contribute to deterioration of the *Titanic*.

Materials

- ❑ Copies of *Electromotive Series Investigation Worksheet*, one for each student group
- ❑ Thin strips of at least three different metals, approximately 1 cm x 5 cm, such as copper, zinc, aluminum, lead, and/or iron; one set for each student group
- ❑ 250 ml beaker or similar-size glass jar; one for each student group
- ❑ Sodium chloride (table salt); approximately 60 grams (2 teaspoons) per student group
- ❑ Digital multimeter capable of measuring 0.01 DC volts (may be shared among several student groups)
- ❑ Insulated jumper leads with alligator clips (such as Radio Shack 278-1156); two for each multimeter
- ❑ Safety goggles, one pair for each student
- ❑ Steel wool or emery paper

Audio-Visual Materials

- ❑ Interactive white board or equivalent

Teaching Time

One 45-minute class period

Seating Arrangement

Classroom style

Maximum Number of Students

30

Key Words

Titanic
Galvanic exchange
Electromotive series
Oxidation
Corrosion

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

At 11:40 pm on April 14, 1912, RMS *Titanic* struck an iceberg off the coast of Newfoundland. Two hours and 40 minutes later, the great liner sank 3,900 meters to the bottom of the North Atlantic Ocean. Thought to be unsinkable, *Titanic* had not survived her maiden voyage. Neither did 1,522 passengers and crew members who also perished on that cold April morning.

In 1985, *Titanic* was seen again by explorers from the Woods Hole Oceanographic Institution and the Institut Français de Recherches pour L'Exploitation des Mers. Using the remotely operated vehicle (ROV) *Argo*, the explorers made dramatic video recordings showing changes brought about by 73 years in the deep ocean. Since the initial discovery in 1985, *Titanic* has been visited by numerous other expeditions, many of which have taken away considerably more than video images. At the end of 2002, an estimated 6,000 artifacts had been removed from the *Titanic* wreck site. These activities have stirred controversy, since the *Titanic* shipwreck is unquestionably a gravesite as well. This fact is underscored by video images of paired shoes (for example, at http://www.titanic-facts.com/titanic-artifacts.html) lying on the ocean floor in positions that suggest the shoes have not moved since the person wearing them landed on the bottom.

Images from Page 1 top to bottom:
A view of the bow of the RMS *Titanic*. Image copyright Emory Kristof/National Geographic.
http://oceanexplorer.noaa.gov/explorations/04titanic/media/hirez/titanic_bow_hirez.jpg

This mosaic of the *Titanic's* bow section was originally published in the October 1987 issue of *National Geographic Magazine*. An updated mosaic will be made from images collected by the *Hercules* ROV during this expedition. Image courtesy of Bert Fox © National Geographic Society.
http://oceanexplorer.noaa.gov/explorations/04titanic/slideshows/june02/slideshow.html#

Institute for Exploration (IFE) engineer Dave Lavalvo (in red) removes a rusticle experiment station from the *Hercules* "bio box" and hands it to microbiologist Dr. Roy Cullimore, who placed it on the *Titanic's* bow in 1998 for future rusticle analysis. It was retrieved from the depths on June 2, 2004. Image courtesy of Mike Sweeney © National Geographic Society.
http://oceanexplorer.noaa.gov/explorations/04titanic/slideshows/june03/slideshow.html#

A view of the steering motor on the bridge of the *Titanic*. Image copyright Emory Kristof/National Geographic.
http://oceanexplorer.noaa.gov/explorations/04titanic/media/hirez/steering_motor_bridge_hirez.jpg

In addition to damage caused by recent human activities, the remains of *Titanic* have been subjected to more than 90 years of natural degradation processes as well. One of the most conspicuous processes is caused by complex communities of bacteria and fungi that produce structures called "rusticles" that superficially resemble icicles or stalactites. Rusticles are built up in ring structures and are highly porous with channels and reservoirs that allow water to flow through. Up to 35% of rusticles' mass consists of iron compounds (iron oxides, iron carbonates, and iron hydroxides). The remainder is biomass of bacteria and fungi. Rusticles grown in laboratories have been found to continuously release a red, powder-like material as well as a yellowish slime. The iron content of these materials is 20 ± 5% and 8 ± 3%, respectively. These releases total between 0.02% and 0.03% of the rusticles' biomass per day. Based on these observations, it has been estimated that all of the iron in *Titanic's* bow section could be removed in approximately 280 to 420 years. Experiments are underway at the *Titanic* site to measure the actual rate of iron removal from the ship due to rusticles. Whatever the rate, it is clear that *Titanic* is slowly being recycled back to nature.

Another natural degradation process known as "galvanic exchange" (or "galvanic coupling" or "galvanic corrosion") is also at work on *Titanic*. This process results from different metals in electrical contact with each other in seawater. Metals can be classified into an "Electromotive Series" according to the strength with which they "hold on" to their electrons. Metals lower in the Series tend to give up their electrons more readily than metals that are higher in the Series. When two metals with different electromotive strengths are electrically connected and submerged in an electrolyte (such as seawater), electrons will flow from the metal lower in the electromotive series, causing this metal to form oxides or other compounds in a process we know as corrosion (this is also the process through which batteries produce an electric current). Besides the iron in its hull, *Titanic* contains many other metals such as lead, bronze, copper, and brass that are higher in the Electromotive Series than iron. As a result, the steel in *Titanic's* hull is degraded as iron is replaced by other compounds formed through galvanic exchange.

It has been suggested that galvanic exchange was the real reason Titanic sank in the first place. Since the ship was held together by 3 million rivets made with wrought iron (which is a different material than the hull plates), galvanic exchange could have taken place between the dissimilar metals of the hull and rivets causing the rivets to weaken. In fact, Titanic sat in seawater for a year after her hull was launched while the interior was furnished. One of the last photos taken before the ship's maiden voyage shows a pattern that may suggest the rivets were rusting faster than the hull plates. When Titanic collided with the iceberg, the weakened rivets could have popped (which would account for a clinking sound reported by some survivors). An opening just an inch wide between the hull plates would have been enough to sink the ship...and video images of the wreckage show a narrow opening in the unburied part of the bow, as well as preferential corrosion of the rivets in some areas. For more information on this theory, visit http://www.corrosion-doctors.org/Landmarks/titan-sinking.htm.

The mission of the 2004 Return to *Titanic* Expedition was to assess changes that occurred at the RMS *Titanic* wreck site since 1985, and to investigate natural degradation processes as well as changes caused by human activity.

In this lesson, students will investigate the chemical activity of several metals, and use their observations to arrange the metals in an Electromotive Series.

Learning Procedure

NOTE: Goggles and protective gloves should be worn throughout portions of the activity involving work with metal strips and salt solutions. Be sure students wash their hands thoroughly following this activity to minimize exposure to heavy metals.

1. To prepare for this lesson:
   a. Clean metals with steel wool or emery paper to remove any surface oxide coatings that might interfere with the measurements.

   b. Download a copy of the press release, *Return to Titanic Mission to Document Wreck's Destruction* from http://news.nationalgeographic.com/news/2004/04/0423_040423_titanicscience.html. Capture the title and first paragraph for display on an interactive white board or video projector. You may also want to include an image of Titanic's exterior, such as http://oceanexplorer.noaa.gov/explorations/04titanic/media/hirez/titanic_bow_hirez.jpg.

   c. Review http://oceanexplorer.noaa.gov/explorations/03titanic/welcome.html and http://oceanexplorer.noaa.gov/explorations/04titanic/welcome.html for information on the R.M.S. *Titanic* 2003 and 2004 Expeditions, respectively.

   d. To save class time, you may want to prepare the salt solution (Step 4) in advance. Each student group will require about 200 ml of the solution.

2. Briefly review the history of *Titanic*, its sinking, discovery of the shipwreck in 1985, and human activities at the site following this discovery. Show students the captured images (Step 1b), and ask

what processes might be responsible for the alarming and possibly increasing rate of deterioration. Students should recognize that both natural and human-induced processes may be involved, and may distinguish between galvanic action and "rusting." If you have serious *Titanic* fans in your class, they may also know about rusticles.

3. Review the concept of oxidation and reduction. Be sure students understand that the term "oxidation" means loss of electrons. While oxygen is often involved in this process, oxidation can also take place in the absence of oxygen. Tell students that they are going to make observations that should allow them to classify different metals according to how easily the metals give up their electrons.

4. Provide each student group with a copy of the *Electromotive Series Investigation Worksheet* and ensure that each group has access to the materials listed on the *Worksheet*. Have students complete the described procedures and record their observations on the *Worksheet*. Note that students are only asked to record which metal is reduced (has greater reduction potential) for each pair of metals tested. Students are not asked to record the voltages measured, since many inexpensive multimeters are not sensitive enough to obtain accurate measurements.

5. Show students an electromotive series from a chemistry textbook, and have them compare this information to their own results. Discuss the following questions:
   a. Boats often have bars of zinc attached to metals parts below the water. Why? [Zinc is low in the electromotive series, so zinc loses its electrons more easily than other metals and protects these metals from corrosion.]
   b. Bronze is slightly higher than copper on the electromotive scale. What would happen if a bronze propeller were attached to a steel drive shaft on a ship? [The shaft would corrode because steel is lower in the electromotive series than bronze.]
   c. How could this be prevented? [by attaching zinc to the drive shaft]
   d. What would happen if a zinc-plated steel washer were used underwater with a stainless steel bolt? [The zinc would eventually corrode away, allowing the steel washer to rust and weaken the connection.]
   e. List five items that might be found on *Titanic* that you would expect to experience little or no corrosion. [any metallic items made from bronze, copper, gold, or silver; as well as durable non-metallic items such as china or glass; artifacts removed from the ship also include shoes and clothing]

The BRIDGE Connection

www.vims.edu/bridge/ – In the Navigation toolbar, click on "Ocean Science Topics," then "Human Activities," then "Heritage", then "Archeology". Also, search keyword "*Titanic*" in the "Search" box for more locations on the BRIDGE site dealing with *Titanic* topics.

The "Me" Connection

Have students write a short essay describing ways in which corrosion might affect their own lives, and what is (or could be) done to avoid these impacts.

Connections to Other Subjects

English/Language Arts, Social Studies, Life Science

Assessment

Student reports in Steps 5 and 6 provide opportunities for assessment.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov/explorations/04titanic/welcome.html to find out more about the 2004 Return to *Titanic* Expedition.
2. Have students investigate initiatives to protect the wreck of *Titanic*, and discuss the merits of salvage vs. protection.
3. Have students investigate one or more persons who were aboard *Titanic* when the ship sank, and prepare a report on their activities on April 14 and 15, 1912.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://www.corrosion-doctors.org/ – A web site about corrosion causes and solutions, with modules designed for training in corrosion science and engineering

http://www.encyclopedia-titanica.org — Encyclopedia *Titanic*a web site with biographies, research articles and ongoing discussions about the *Titanic*

http://www.titanic-nautical.com/RMS-Titanic.html – Titanic Web page from the Titantic and Nautical Resource Center

http://score.rims.k12.ca.us/activity/bubbles/ – Marine archaeology activity guide based on investigations of the wreck of a Spanish galleon; from the Schools of California Online Resources for Education website

http://www.titanic1.org/ – *Titanic* Historical Society

http://www.titanicinquiry.org/ – *Titanic* Inquiry Project

http://www.skarr.com/titanic/ – The *Titanic* Information Site

http://www.titanicscience.com/TSci-ActivityGuideFinal.pdf – Maryland Science Center's *Titanic* Science Teacher Activity Guide

http://www.encyclopedia-titanica.org/deckplan/index/ – Deck plans for *Titanic*

also http://www.copperas.com/titanic/ – Deck plans for *Titanic*, as well as a link to a detailed description of *Titanic* published in the May 26, 1911 issue of the British journal "Engineering"

Archbold, R. and D. McCauley. 1997. *Last Dinner on the Titanic.* Madison Press. Toronto.

Ballard, R. D. with R. Archbold. 1995. *The Discovery of the Titanic.* Warner Books. New York.

Ballard, R. D. 1985. *How we found Titanic.* National Geographic Magazine 168(6):696-719

Ballard, R. D., with M. Sweeney. 2004. *Return to Titanic*. National Geographic. Washington, DC.

Macaulay, D. 1993. *Ship*. Houghton Mifflin Company. Boston.

Lord, W. 1986. *The Night Lives On*. William Morrow and Company, Inc. New York.

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

Send Us Your Feedback

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818
843.762.8737 (fax)
paula.keener-chavis@noaa.gov

Acknowledgements

This lesson was developed and written for NOAA's Office of Ocean Exploration and Research (OER) by Dr. Mel Goodwin, Science and Technology Consultant to OER's Education Team.
Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

Credit

If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov

Electromotive Series Investigation Worksheet

Materials

- ❑ Thin strips of various metals provided by your teacher
- ❑ 250 ml beaker or similar-size glass jar
- ❑ Sodium chloride (table salt) or premixed solution provided by your teacher
- ❑ Digital multimeter
- ❑ 2 - Insulated jumper leads with alligator clips
- ❑ Safety goggles
- ❑ Steel wool or emery paper

Procedure

1. In a 250 ml beaker, make a salt solution by dissolving about 60 grams of sodium chloride in 100 ml of water (you can use tap water or distilled water for this solution). If your teacher has provided a premixed salt solution, pour about 100 ml of this solution into the beaker.

2. Write the names of the metals in the top row and in the left column of Table 1.

3. Connect the alligator clip on one end of each jumper lead to the test leads attached to the multimeter. Set the multimeter to measure millivolts (0.001 v).

4. Connect the alligator clip on one of the jumper leads to one of the metal strips, and connect the alligator clip on the other jumper lead to another metal strip.

5. Hold both of the metal strips in the salt solution so that they are about 2 cm apart, then read the voltage on the multimeter. If the voltage reading is negative, reverse the jumper leads attached to the metal strips so that the reading is positive.

6. The test lead attached to the negative terminal on the multimeter is connected to the metal that is providing (losing) electrons; so this metal is being oxidized. The test lead attached to the positive terminal on the multimeter is connected to the metal that is accepting electrons; so this metal is being reduced. The metal that is being reduced has a higher reduction potential than the metal being oxidized. Find the line in Table 1 that corresponds to the two metals you tested, and write the name of the metal that is being reduced on the line.

7. Repeat Steps 4, 5, and 6 for all of the possible pairs of metals.

8. Arrange the metals you tested in a list so that the metal with the highest reduction potential is at the top of the list, the metal with the next highest reduction potential is second on the list, and so on until the metal with the lowest reduction potential is at the bottom of the list. The more times a metal is listed in Table 1, the higher its reduction potential compared to the other metals. This kind of list is called an electromotive series. Metals that are lower in the electromotive series tend to lose their electrons more easily than metals that are higher in the series. Losing electrons can cause metals to deteriorate, and this process is called corrosion.

Table 1
Relative Reduction Potential of Tested Metals

For each pair of metals,place the name of the metal with the higher reduction potential onto the blue line in the table.

	______ (Metal 1)	______ (Metal 2)	______ (Metal 3)
______ (Metal 2)	______		
______ (Metal 3)	______	______	
______ (Metal 4)	______	______	______

Electromotive Series of Tested Metals

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________