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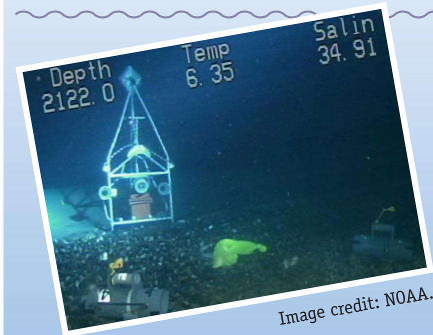
Bioluminescence 2009:
Living Light on the Deep Sea Floor Expedition

Living Light



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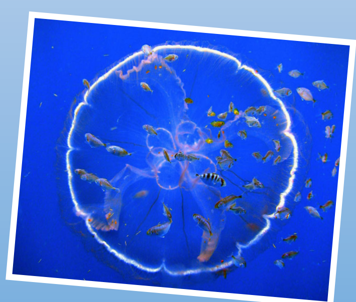

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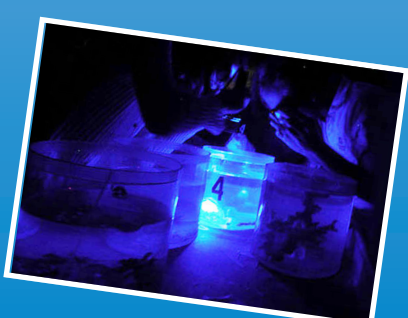


Image credit: NOAA.

Image captions on Page 2.

lesson plan

Focus
Bioluminescence

Grade Level
9-12 (Chemistry/Life Science)

Focus Question
What organisms exhibit bioluminescence, how does this process benefit deep-sea organisms, and what is the chemical basis for this phenomenon?

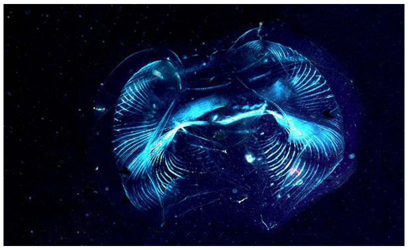
Learning Objectives
- Students will be able to explain the overall process of bioluminescence, including the role of luciferins, luciferases, and cofactors.
- Students will be able to discuss at least three phyla that include bioluminescent organisms.
- Students will be able to discuss at least three ways that bioluminescence may benefit deep-sea organisms, and give an example of at least one organism that actually receives each of the benefits discussed.
- Students will be able to create a scientific poster to communicate technical information.

Materials
- Internet or library access, including capability to download and print images
- Materials for creating scientific posters
- Copies of "Bioluminescence and Scientific Posters Inquiry Guide" – one for each student group

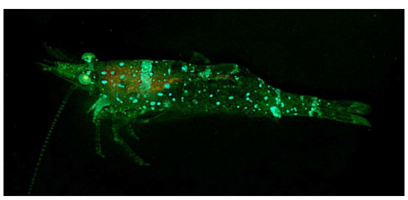
Audio/Visual Materials
- (Optional) Images of deep-sea environments and organisms that use bioluminescence (see Learning Procedure)

Teaching Time
Two 45-minute class periods, plus time for student research

Seating Arrangement
Groups of 3-4 students



The lobate ctenophore *Ocyropsis maculata* as viewed under unpolarized light (top) and polarized light (bottom). Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug27/media/ocyropsis_unpolarized_600.jpg
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug27/media/ocyropsis_polarized_600.jpg



Unidentified *Sargassum* shrimp bearing two colors of fluorescent patches. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug22/media/fluorescent_shrimp_600.jpg

Images from Page 1 top to bottom:
The Eye-In-The-Sea camera system deployed on the edge of a brine pool, over 2,100 ft deep in the Gulf of Mexico. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug8/media/eye_600.jpg

A flotilla of fish follow a transparent drifting jellyfish, *Aurelia aurita*. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/sep3/media/aurelia3_rs_600.jpg

The pontellid copepod *Pontella securifer*. Various parts glow fluorescent green when viewed under blue light. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug26/media/horned_copepod_mf_600.jpg

Deep Scope 2005 science crew examines recently collected specimens. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/sep4/media/examining_specimens_600.jpg

Maximum Number of Students
30

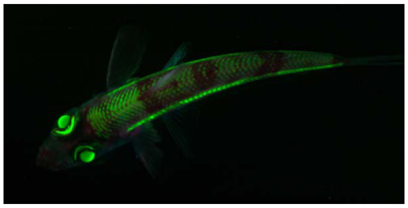
Key Words
Chemiluminescence
Bioluminescence
Luciferin
Luciferase
Photoprotein
Counter-illumination

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 usually will need to adapt the language and instructional approach to styles that are best suited to specific student groups.*]

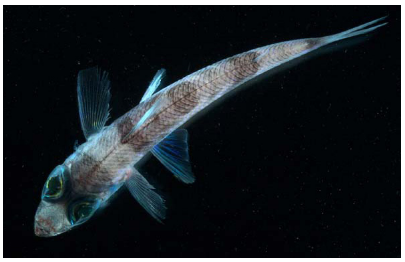
Deep ocean environments are almost completely dark; yet light is still important in these environments. Many marine species are able to produce "living light" through a process known as bioluminescence, but very little is known about specific ways that deep-sea organisms use this ability. Part of the problem is that these organisms are difficult to observe: turning on bright lights can cause mobile animals to move away, and may permanently blind light-sensitive sight organs. In addition, transparent and camouflaged organisms may be virtually invisible even with strong lights, and many types of bioluminescence can't be seen under ordinary visible light. Overcoming these obstacles is a primary objective of the Bioluminescence 2009: Living Light on the Deep Sea Floor Expedition.

Like the 2004 and 2005 Ocean Exploration Deep Scope Expeditions (http://oceanexplorer.noaa.gov/explorations/04deepscope/welcome.html and http://oceanexplorer.noaa.gov/explorations/05deepscope/welcome.html), Bioluminescence 2009 will use advanced optical techniques to observe animals under extremely dim light that may reveal organisms and behaviors that have never been seen before. In addition, these techniques will allow scientists to study animals whose vision is based on processes that are very different from human vision.

These techniques are based on a number of basic concepts related to the production of light by chemical reactions, a process known as chemiluminescence. When these reactions occur in living organisms, the process is called bioluminescence. A familiar example is the bioluminescence of fireflies; another is "foxfire," which is caused by bioluminescence in fungi growing on wood. Bioluminescence is relatively rare in terrestrial ecosystems, but is much more common



The shortnose greeneye fish gets its name from fluorescent eyes. Image credit: NOAA. http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug16/media/greeneye_fluor_600.jpg



Under white light, the greeneye fish looks very different, but its green lenses are still apparent. Image credit: NOAA. http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug16/media/greeneye_600.jpg

The black loosejaw, *Malacosteus*, is thought to use its suborbital photophores like search lights to find prey. Image credit: Wikipedia.

in marine organisms including bacteria, algae, cnidarians, annelids, crustaceans, and fishes.

The fundamental chemiluminescent reaction occurs when an electron in a chemical molecule receives sufficient energy from an external source to drive the electron into a higher-energy orbital. This is typically an unstable condition, and when the electron returns to the original lower-energy state, energy is emitted from the molecule as a photon. Lightning is an example of gas-phase chemiluminescence: an electrical discharge in the atmosphere drives electrons in gas molecules (such as nitrogen and oxygen) to higher-energy orbitals. When the electrons return to their original lower-energy orbitals, energy is released in the form of visible light. The production of light in bioluminescent organisms results from the conversion of chemical energy to light energy. The energy for bioluminescent reactions is typically provided by an exothermic chemical reaction.

Bioluminescence typically requires at least three components: a light-emitting organic molecule known as a luciferin; a source of oxygen (may be O_2, but could also be hydrogen peroxide or a similar compound); and a protein catalyst known as a luciferase. In some organisms, these three components are bound together in a complex called a photoprotein. Light production may be triggered by the presence of ions (often calcium) or other chemicals. Some bioluminescent systems also contain a fluorescent protein that absorbs the light energy produced by the photoprotein, and re-emits this energy as light at a longer wavelength. Several different luciferins have been found in marine organisms, suggesting that bioluminescence may have evolved many times in the sea among different taxonomic groups. Despite these differences, almost all marine bioluminescence is green to blue in color. These colors travel farther through seawater than warmer colors. In fact, most marine organisms are sensitive only to blue light. An interesting exception is a fish known as the black loosejaw, which can see a variety of colors including red. The loosejaw has a red light-emitting organ beneath its eyes, and is able to use this light to locate prey animals that cannot see red.

This lesson guides student inquiry into bioluminescence in deep-sea organisms, and provides practical experience in constructing scientific posters.

Learning Procedure

1. To prepare for this lesson:
   a. Read:
      – Introductory essays for the Bioluminescence 2009 Expedition (http://oceanexplorer.noaa.gov/explorations/09deepscope/welcome.html);

b. Optional: Download or copy several images showing light and color in deep-sea environments and organisms from one or more of the following Web sites:
http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html
http://www.pbs.org/wgbh/nova/abyss/life/bestiary.html
http://www.lifesci.ucsb.edu/~biolum/

2. Briefly discuss the mission plan and activities of the 2009 Bioluminescence Expedition. You may want to show images of various deep-sea environments and organisms. You may also want to discuss the use and creation of scientific posters. Web sites listed on the Inquiry Guide include links to several PowerPoint® presentations that can be useful if you decide to discuss posters.

3. Provide each student group with a copy of "Bioluminescence and Scientific Posters Inquiry Guide" and instruct them to work through all of the items. You may also want to provide copies of the "Marine Bioluminescence" article, or leave this to students to download on their own.

4. Have each group present their poster. You may want to consider involving other educators or classes in these presentations. For example, you might arrange a poster session that would be attended by one or more other classes whose students would have a checklist of information that they needed to obtain from the poster presentations. This would provide your students with an opportunity to present their findings, as well as provide an introduction to bioluminescence to visiting students.

   You may also want to discuss results of students' inquiries based on the "Marine Bioluminescence" article. These results should include:
   1. Bioluminescence can aid the survival of a marine organism by helping the organism find food, assisting in reproductive processes, and providing defensive mechanisms.
   2. It is important for loosejaw fish to be able to retract their light-producing organs because these organs are highly reflective even when they are not emitting light, and might reveal the fish's presence to predators or prey.
   3. Marine organisms use bioluminescence for defense by temporarily blinding a predator, creating camouflage, and attracting larger predators that may deter an attacker ("burglar alarm" displays).
   4. Many open ocean predators have upturned eyes and an upturned mouth because they detect potential prey when the prey species is silhouetted against light from the sea surface.

5. Define luciferin, luciferase, and cofactor. A luciferin is a light-emitting organic molecule; a luciferase is a protein that catalyzes a light-producing chemical reaction; cofactors are other molecules (e.g., calcium) that must be present for a particular bioluminescent reaction to occur. Note that the "Marine Bioluminescence" article does not explicitly define "cofactor," though it describes their role in bioluminescent reactions. Students will have to research this term elsewhere, or infer its definition from the discussion in the article.
6. The flash of light in bioluminescent systems occurs when an electron in a chemical molecule receives sufficient energy from an external source to drive the electron into a higher-energy orbital and then returns to the original lower-energy state, causing energy to be emitted from the molecule as a photon.
7. All luciferins require oxygen to produce light.
8. The fact that there are many different combinations of chemicals that produce bioluminescence suggests that the ability to produce light has evolved many times in various species.
9. Bacterial bioluminescence is different from most other bioluminescent systems in that it is continuous, rather than being regulated by neural or other control systems.
10. Bioluminescence is a form of chemiluminescence, in which light-producing energy is derived from chemical reactions. Fluorescence and phosphorescence are distinctly different in that they occur when electrons in a molecule are driven to a higher-energy orbital by the absorption of light energy (instead of chemical energy). Atoms of a fluorescent material typically re-emit the absorbed radiation only as long as the atoms are being irradiated (as in a fluorescent lamp). Phosphorescent materials, on the other hand, continue to emit light for a much longer time after the incident radiation is removed (glowing hands on watches and clocks are familiar examples). Both fluorescence and phosphorescence may occur in living organisms.

The BRIDGE Connection

http://www.vims.edu/bridge/ – Type "bioluminescence" in the Search box on the welcome page for links to information and activities related to light producing organisms in the ocean.

The "Me" Connection

Have students write a short essay on how bioluminescence might be potentially important to their own lives.

Connections to Other Subjects

English/Language Arts, Earth Science, Life Science

Assessment

Posters and live presentations provide opportunities for assessment.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov/explorations/09deepscope/welcome.html to keep up to date with the latest discoveries by the Bioluminescence 2009 Expedition.

2. For instructions on how to make your own ultraviolet light source, see the lesson plan "A Bioluminescent Gallery" (Grade level 5-6).

3. To demonstrate the fluorescence of chlorophyll, chop about 150 grams of spinach leaves into small pieces and put into 250 ml beaker with 200 ml acetone. Let the jar stand for 30 minutes, then filter through cheesecloth into a clean clear beaker. Shine a flashlight on one side of the jar, and observe dark red fluorescence. The fluorescence is more intense and visible if the chlorophyll solution is viewed under ultraviolet light. See http://www.woodrow.org/teachers/esi/1999/princeton/projects/uv/classroom.html for additional discussion.

4. *Sources of supplies* – Bioluminescence can be demonstrated with several organisms. Dinoflagellates are widely used; see http://siobiolum.ucsd.edu/Biolum_demos.html and http://www.lifesci.ucsb.edu/~biolum/organism/dinohome.html for sources and demonstration ideas. Carolina Biological Supply, http://www.carolina.com/, provides desiccated ostracods, which they call "sea fireflies". Fotodyne, Inc. offers kits for demonstrating bacterial bioluminescence (see http://www.fotodyne.com/content/main_epd). Ultraviolet lamps and other products for demonstrating chemiluminescence, fluorescence, and phosphorescence are offered by: http://www.24hours7days.com/Science/Blacklight_Items.html; http://www.glowspace.com/; http://www.nightsea.com/; http://www.flinnsci.com. *NOTE: Mention of commercial products, Web sites, and/or proprietary names does not constitute endorsement by NOAA.*

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the link to Lesson 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Benthos.

Other Relevant Lessons from NOAA's Ocean Exploration and Research Program

Where Is That Light Coming From?
http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/WhereisLight.pdf
(6 pages, 208Kb) (from the Operation Deep Scope 2004 Expedition)

Focus: Bioluminescence

In this activity, students explain the role of luciferins, luciferases, and co-factors in bioluminescence and the general sequence of the light-emitting process. Additionally, students discuss the major types of luciferins found in marine organisms, define the "lux operon" and discuss at least three ways that bioluminescence may benefit deep-sea organisms. Students give an example of at least one organism that actually receives each of the benefits discussed.

The Eyes Have It!
http://oceanexplorer.noaa.gov/explorations/05deepscope/background/edu/media/eyes.pdf
(6 pages, 287Kb) (from the Operation Deep Scope 2005 Expedition)

Focus: Vision in crustaceans

Students will be able to describe the overall structure of the crustacean compound eye; describe the eyes of stomatopods, and list three of their visual capabilities; and explain why most vertebrates are unable to detect polarized light, while this ability is more common among some invertebrate groups. Students will also be able to discuss three ways in which animals may benefit from polarization vision.

Light at the Bottom of the Deep, Dark Ocean???
http://oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_light.pdf
(8 pages, 476k) (from the 2002 Islands in the Stream Expedition)

Focus: Biology - Adaptations of deepwater organisms

In this activity, students will participate in an inquiry activity; relate the structure of an appendage to its function; and describe how a deepwater organism responds to its environment without bright light.

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://oceanexplorer.noaa.gov/explorations.09deepscope/welcome.html – The Bioluminescence 2009 Expedition Web site

http://www.lifesci.ucsb.edu/~biolum/ —The Bioluminescence Web Page http://www.bioscience-explained.org/ENvol1_1/pdf/BiolumEN.pdf – Marine bioluminescence by Edith A. Widder; Bioscience Explained; Vol 1:1.

http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html – Ocean Explorer photograph gallery

http://www.bioscience-explained.org/ENvol1_1/pdf/PhotoEN.pdf – Bacterial Illumination, by Madden, D. and B.-M. Lidesten; Bioscience Explained; Vol 1, No. 1; Procedures for Culturing Bioluminescent Bacteria

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

- Structure of atoms
- Properties and changes of properties in matter
- Chemical reactions

Content Standard C: Life Science

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

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 resources

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

Essential Principle 7.
The ocean is largely unexplored.
Fundamental Concept a. The ocean is the last and largest unexplored

place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson, including how you are using it in your formal/informal education setting.
Please send your comments to:
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Living Light

Bioluminescence and Scientific Posters Inquiry Guide

Your assignment is to prepare a scientific poster that will provide an introduction to bioluminescence. Tips for producing scientific posters are provided on the next page.

A. Research

The following guidance questions are based on the "Marine Bioluminescence" article at http://www.bioscience-explained.org/ENvol1_1/pdf/BiolumEN.pdf.

1. What are three ways that bioluminescence can aid the survival of a marine organism?
2. Why might it be important for loosejaw fish to be able to retract their light-producing organs instead of simply switching light production on and off?
3. What are three ways that marine organisms use bioluminescence for defense?
4. Why do many open ocean predators have upturned eyes and an upturned mouth?
5. Define luciferin, luciferase, and cofactor.
6. What causes the flash of light in bioluminescent systems?
7. What is one thing that all luciferins have in common?
8. What evolutionary inference is suggested by the fact that there are many different combinations of chemicals that produce bioluminescence?
9. How is bacterial bioluminescence different from most other bioluminescent systems?
10. How is bioluminescence different from fluorescence and phosphorescence?

B. Interpret and Communicate

Prepare a scientific poster that includes the following information:

- *What Organisms Employ Bioluminescence?* – Give examples from at least four phyla
- *How is Bioluminescence Used?* – Give examples of the role of bioluminescence in defense, reproduction, and feeding
- *How Does Bioluminescence Work?* – Describe the overall mechanism; define luciferin, luciferase, and cofactor; give at least three different examples of each

Living Light

Bioluminescence and Scientific Posters Inquiry Guide - continued

Scientific Posters

Scientific posters are an increasingly popular way to communicate results of scientific research and technical projects. There are a number of reasons for this, including limited time at conferences for traditional public speaking-style presentations, better options for interacting one-on-one with people who are really interested in your work, opportunities for viewers to understand the details of your work (even if you aren't present), and having a more relaxed format for those who dislike speaking in public. In addition, posters are more durable than one-time presentations; once they are created they can be used in many different settings, over and over again. For more discussion of pros and cons, as well as examples of good and bad posters, visit

http://www.swarthmore.edu/NatSci/cpurrin1/posteradvice.htm
http://www.ncsu.edu/project/posters/NewSite/
http://www.the-aps.org/careers/careers1/GradProf/gposter.htm

Scientific posters usually contain the same elements as traditional written reports: title, introduction, materials and methods, results, conclusions, literature cited (key citations only!), acknowledgments, and contact points for further information. Good posters do NOT usually have an abstract, though an abstract is often required as part of the submission process and may be included in a printed program.

Another similarity to traditional reports is that the best posters almost always go through several drafts. You should always expect that the first draft of your poster will change significantly before it emerges in final form. Be sure to allow enough time for others to review your first draft and for you to make needed changes.

An important difference (and advantage) that posters have compared to written reports is that posters can be much more flexible in terms of layout and where the elements appear, as long as there is a clear and logical flow to guide viewers through your presentation. Here are a few more tips for good scientific posters (see the Web sites listed above for many other ideas):

- Posters should be readable from 6' away;
- Be sure to leave white space (35% is not too much) – densely packed posters can easily repel potential viewers;
- Like real estate, location is key – the top and right columns of your poster are prime areas for vital material, while the bottom edge will receive much less attention;
- Serif fonts (e.g., Times) are easier to read than sans serif fonts (e.g., Helvetica), so use sans serif fonts for titles and headings, and serif fonts for body text (usually no more than two font families on a single poster)
- Text boxes are easiest to read when they are about 40 characters wide