Bioluminescence 2009:
Living Light on the Deep Sea Floor Expedition

Deep Lights

www.oceanexplorer.noaa.gov

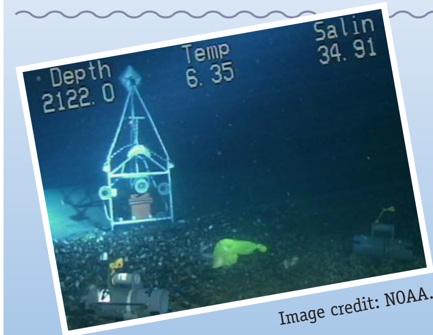
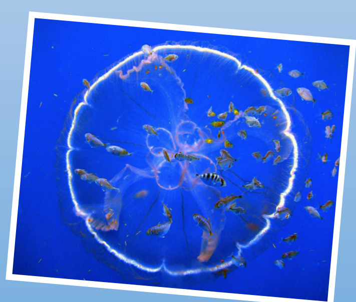


Image credit: NOAA.



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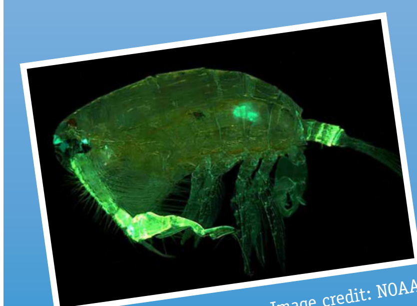


Image credit: NOAA.

Image credit: NOAA.

Image captions on Page 2.

lesson plan

Focus
Light-producing processes and organisms in deep-sea environments

Grade Level
7-8 (Life Science/Physical Science)

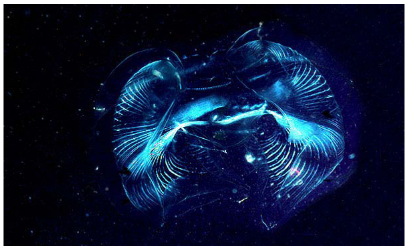
Focus Question
How do deep-sea organisms produce light in deep ocean environments?

Learning Objectives
- Students will be able to compare and contrast chemiluminescence, bioluminescence, fluorescence, phosphorescence, and triboluminescence.

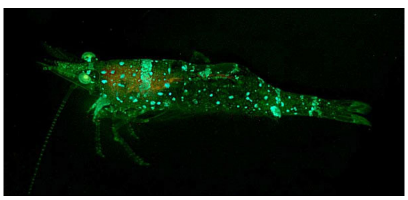
- Given observations on materials that emit light under certain conditions, students will be able to infer whether the light-producing process is chemiluminescence, fluorescence, phosphorescence, or triboluminescence.

- Students will be able to explain three ways in which the ability to produce light may be useful to deep-sea organisms.

Materials
- Ultraviolet lamp (see Extensions)
- Materials for demonstrating fluorescence, phosphorescence, chemiluminescence, and triboluminescence; see "Learning Procedure" Step 1b and "Extensions" for a partial list of suppliers
- Watch glasses, petri dishes, bottle caps, or similar containers to hold small samples of solid materials
- Clear glass 50 ml beakers, graduated cylinders, or similar containers for liquid materials
- Plastic sandwich bags, two for each student group
- Pliers; one for each student group, or groups may share
- One or more large cardboard cartons to provide a darkened space for viewing materials under ultraviolet light, if the classroom does not have a space that can be darkened sufficiently
- Copies of "Light in the Deep Ocean Inquiry Guide," one copy for each student group



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

Audio/Visual Materials

(Optional) Images showing light and color in deep-sea environments and organisms (see Learning Procedure, Step 1c)

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Classroom style if students will be working individually or groups of two to four students

Maximum Number of Students

30

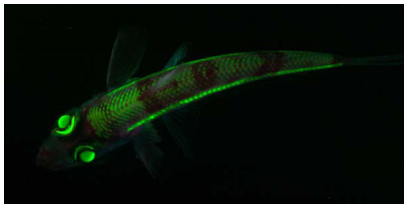
Key Words

Light
Chemiluminescence
Bioluminescence
Fluorescence
Phosphorescence
Triboluminescence
Luciferin
Luciferase
Photoprotein
Counter-illumination

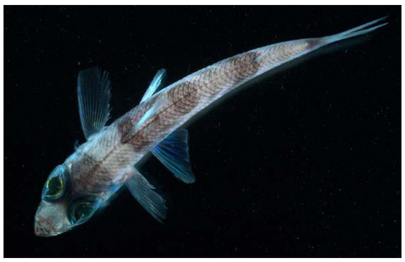
Background Information

[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.



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

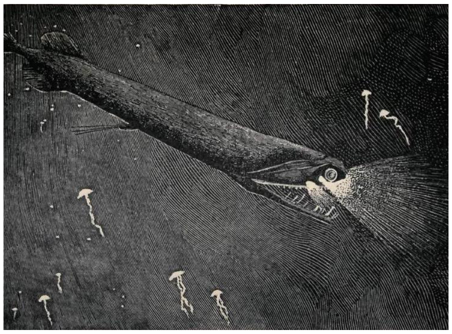


Under white light, the greeneye fish looks very different, but its green lenses are still apparent. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug16/media/greeneye_600.jpg

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 in the 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



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

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.

Fluorescence and phosphorescence are distinctly different from chemiluminescence. These light-producing processes 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.

Triboluminescence is another light-producing process that takes place when physical stress is applied to certain crystals, such as knocking two quartz rocks together. The mechanical energy from stressing the crystals provides energy that raises electrons in the crystals' molecules to a higher-energy orbital. When the electrons return to a lower-energy state, light energy is emitted from the molecules.

This lesson guides student inquiry into chemiluminescence, fluorescence, phosphorescence, and triboluminescence. Demonstrations of bioluminescence are also possible, but require additional preparation and class time. Sources of information and supplies are provided under "Extensions."

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. Assemble materials that have fluorescent, phosphorescent, or triboluminescent properties for student inquiries. Fluorescent materials include powder laundry detergent; quinine ("tonic") water; fluorescent paints, markers, or crayons; B vitamins dissolved in water; and fluorescent minerals. Phosphorescent ("glow in the dark") materials may be obtained from stores that sell Halloween decorations or educational supplies as well as from the indicated suppliers listed under "Resources". Small quantities of these materials should be placed in individual watch glasses, petri dishes, or bottle caps. Liquid materials should be placed in clear glass 50 ml beakers, graduated cylinders, or similar containers. Wintergreen-flavored candy can be used to

demonstrate triboluminescence. Lightsticks (or the glow-in-the-dark bracelets and necklaces) are convenient demonstrations of chemiluminescence. It is a good idea to test your selections under ultraviolet light before distributing the materials to students so that you have an idea of what to expect. **CAUTION: Never look directly at an exposed ultraviolet light source!**

c. 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.

3. Provide each student group with a copy of “Light in the Deep Ocean Inquiry Guide,” and a collection of materials to be tested. Have each group complete the activites and answer the questions on the Guide. Groups may have to take turns using the ultraviolet lamp and darkened viewing area. REMIND STUDENTS NOT TO LOOK DIRECTLY AT AN EXPOSED ULTRAVIOLET LIGHT SOURCE.

   If time and/or materials are limited, Part B of the Inquiry Guide may be conducted as a demonstration for the entire class, however each group should record and analyze their observations independently.

4. Discuss results of students’ inquiries.

   A. Be sure students understand the distinction between chemiluminescence, bioluminescence, fluorescence, phosphorescence, and triboluminescence and that all of these processes involve molecules that receive energy from an external source, some of which is absorbed by electrons in the molecules. The added energy causes the electrons to be temporarily raised to a higher-energy orbital. When the electrons return to their original energy state, some of the absorbed energy is emitted as light energy.

   B & C. The lightsticks are examples of chemiluminescence. Flexing a light stick breaks a thin glass ampoule inside the stick, releasing hydrogen peroxide. The hydrogen peroxide reacts with an oxalic phthalate ester, releasing a high-energy molecule that energizes dye molecules that are also contained in the light stick. The dye molecules subsequently release this additional energy as a photon of light, causing a glow whose color depends upon the specific dye used in the light stick system. Students should observe that dye molecules can also be energized by ultraviolet light, and in this case, are also an example of fluorescence.

Fluorescence is demonstrated by objects that produce light only while being irradiated with the ultraviolet lamp. Phosphorescence is demonstrated by objects that continue to glow after an external light source is removed. Be sure students realize that energy for phosphorescent light always comes from an external light source at some time before phosphorescence actually begins.

Students may have observed that their own clothing (particularly white clothing) glows blue under ultraviolet light. The explanation for this is that some laundry detergents contain additives that makes clothes look "whiter" by absorbing ultraviolet light energy from sunlight then emitting blue fluorescent light. Quinine ("tonic") water also fluoresces under ultraviolet light.

When wintergreen candy is crushed, the mechanical stress causes flashes of light, providing an example of triboluminescence. Students may also have seen weaker flashes when sugar cubes are crushed; in both cases the triboluminescent molecules are sugar (sucrose). The flashes from sugar alone appear much less bright than those from the candy, because a lot of the light emitted when sucrose molecules are crushed is in the ultraviolet portion of the spectrum, which is not visible to human eyes. Flashes from crushing the candy appear brighter because wintergreen flavor (methyl salicylate) is fluorescent. Methyl salicylate molecules absorb ultraviolet light generated by crushed sucrose, then emit some of the energy as blue light in the visible region of the spectrum.

D. Since explorations of deep-sea communities are just beginning, we probably don't know all of the ways that light-producing processes are used by deep-sea organisms. We do know that some organisms seem to use bioluminescence to locate other members of the same species, and we infer that this would be useful for mating activities.

(1) Bioluminescence may also be useful for feeding. Some organisms (such as the angler fish) use bioluminescence to attract prey species. Others (such as fishes in the malacosteid family) have a "floodlight" system that allows them to see nearby organisms. These fishes have organs that produce red

light (an exception to the “blue only” rule), as well as eyes that can detect red light. Since most other species (as far as we know) cannot see red light, the malacosteids can easily sneak up on their prey.

A third potential use for bioluminescence is camouflage. It may not be immediately obvious how emitting light could make an organism less visible, yet this is the strategy involved in counter-illumination. You can illustrate this by holding a white index card against a window in a darkened room. The card will block out light coming through the window and be visible as a darker object against the bright background. If you shine a flashlight on the card, the illumination on the “dark” side of the card will more closely resemble that of the background, making the card less visible. Counter-illumination could thus be a useful strategy to a swimming organism trying to be less visible to a potential predator swimming below.

Some animals use bioluminescence for defense in a different way. Some tube-dwelling worms spew out clouds of glowing blue material when they are threatened. The strategy is similar to the fear scream of monkeys or birds, which are intended to attract the attention of higher order predators that may attack the threatening predator. So glowing clouds produced by the worm exposes the threatening invader and makes the invader vulnerable to attack by a higher order predator.

(2) One explanation for the fact that most marine bioluminescence is blue or blue-green is that light at the blue end of the spectrum has higher energy than light at the red end of the spectrum, and thus has greater power to penetrate seawater. It is also true that most marine organisms only appear to be able to detect blue light.

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 research on light-producing organisms in deep-sea environments could be of direct personal benefit. This does not have to be based on actual discoveries that have already been made (though this is fine, too), but may also be what MIGHT happen, and what events or discoveries would link these organisms to their own life.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Students' answers to Inquiry Guide questions and class discussions 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 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

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

- Properties and changes of properties in matter

Content Standard C: Life Science

- Structure and function in living systems
- Diversity and adaptations of organisms

Content Standard E: Science and Technology

- Abilities of technological design

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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Acknowledgements

This lesson plan was produced by Mel Goodwin, PhD, The Harmony Project, Charleston, SC for the National Oceanic and Atmospheric Administration. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov

Deep Lights

Light in the Deep Ocean Inquiry Guide

A. Web Inquiry

Compare and contrast: chemiluminescence, bioluminescence, fluorescence, phosphorescence, triboluminescence.

B. Explore and Observe

1. Observe each of the materials provided by your teacher under ordinary room light, then under ultraviolet light, and finally in darkness. Record the appearance of each material under each lighting condition on the data sheet. When examining liquids under ultraviolet light, shine the light from above the container and observe the liquid from the side.
   CAUTION: Never look directly at an ultraviolet light source!

2. Bend the lightstick until the glass ampoule inside the plastic tube breaks, shake the lightstick briefly, and record your observations. Observe the activated lightstick again under ultraviolet light, and record its appearance.

3. In a dark chamber or dark room, put a sugar cube in a plastic bag, crush the sugar with pair of pliers, and record your observations. Repeat with a piece of wintergreen candy.

C. Analyze

How do you explain your observations in Part B? Which of your observations provide examples of chemiluminescence, bioluminescence, fluorescence, phosphorescence, triboluminescence?

Deep Lights

Light in the Deep Ocean Inquiry Guide - continued

D. Infer

1. How might light-producing processes be useful to organisms living in the deep ocean?

2. Most marine bioluminescence is blue or blue-green. What are some possible explanations for this?

Deep Lights

Light in the Deep Ocean Inquiry Data Sheet

Material	Appearance		
	Room Light	Ultraviolet Light	Darkness