ocean explorer
oceanexplorer.noaa.gov

2004 Deep-Scope Expedition

Cool Lights

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

Grade Level
5-6 (Life Science & Physical Science)

Focus Question
How and why do deep-sea organisms produce light, and how can these processes be used to study life in deep ocean environments?

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

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

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

Students will be able to explain how scientists may be able to use light-producing processes in deep-sea organisms to obtain new observations of these organisms.

Materials
- ❑ Ultraviolet lamp (see Resources)
- ❑ Materials for demonstrating fluorescence and phosphorescence (see Learning Procedure)

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

Teaching Time
One 45-minute class period; more if demonstrations of bioluminescence are included

Seating Arrangement
Classroom style

Maximum Number of Students
30

Key Words
Chemiluminescence
Bioluminescence
Fluorescence
Phosphorescence
Luciferin
Luciferase
Photoprotein
Counter-illumination

Background Information
Deep-sea explorers face many challenges: extreme heat and cold, high pressures, and almost total darkness. The absence of light poses particular challenges to scientists who want to study organisms that inhabit the deep ocean environment. Even though deep-diving submersibles carry bright lights, simply turning these lights on creates another set of problems: at least some mobile organisms are likely to move away from

the light; organisms with light-sensitive organs may be permanently blinded by intense illumination; even sedentary organisms may shrink back, ceasing normal life activities and possibly becoming less noticeable; and small cryptic organisms may simply be unnoticed. In addition, some important aspects of deep-sea biology simply can't be studied with ordinary visible light. Many marine species are known to be capable of producing light, and it is reasonable to suppose that ability to produce and detect light might be particularly important to organisms that live in near-total darkness.

The primary purpose of the 2004 Ocean Exploration Deep-Scope Expedition is to study deep-sea biological communities using advanced optical techniques that provide new ways of looking at organisms that make their home in the blackness of the deep ocean. These techniques are based on a number of basic concepts that can be summarized under the general heading of "bioluminescence."

Bioluminescence is a form of chemiluminescence, which is the production of visible light by a chemical reaction. When this kind of reaction occurs in living organisms, the process is called bioluminescence. It is familiar to most of us as the process that causes fireflies to glow. Some of us may also have seen "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 environment. Marine organisms producing bioluminescence include bacteria, algae, coelenterates, 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 N_2 and O_2) to higher-energy orbitals. When the electrons return to their original lower-energy orbitals, energy is released in the form of visible light.

Chemiluminescence is distinctly different from fluorescence and phosphorescence, which occur when electrons in a molecule are driven to a higher-energy orbital by the absorption of light energy (instead of chemical energy). Both processes may occur in living organisms. 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). Chemiluminescent reactions, on the other hand, produce light without any prior absorption of radiant energy. Another light-producing process known as triboluminescence occurs in certain crystals when mechanical stress applied to the crystal provides energy that raises electrons to a higher-energy orbital.

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.

In this activity, students will explore chemiluminescence, and develop inferences about how this process may be useful to organisms living in the deep ocean. These activities may be done as a demonstration involving the entire class, or as investigations by groups of three or four students, depending upon the availability of materials and equipment.

Learning Procedure

1. Assemble materials for demonstrations or student investigations. Suitable materials for demonstrating fluorescence include laundry detergent; Murine eye drops; Pearl Drops® toothpaste; Sensodyne® toothpaste; Vaseline®; Silver Fox® shampoo; fluorescent paints, markers, or crayons; 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."

   If you want to show images of deep-sea environments and organisms that use bioluminescence, the following web sites are useful resources:
   http://www.biolum.org/
   http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html
   http://www.europa.com/edge.of.CyberSpace/deep.html
   http://www.europa.com/edge.of.CyberSpace/deep2.html
   http://www.pbs.org/wgbh/nova.abyss/life.bestiary.html
   http://biodidac.bio.uottawa.ca/
   http://www.fishbase.org/search.cfm

2. Ask students to describe characteristics of deep-sea environments (depth = 1,000 meters or more). You may want to show images of various deep-sea environments and organisms that use bioluminescence.

   Focus the discussion on light in the deep ocean. Students should realize that light is almost completely absent. Ask whether plants and animals are ever able to produce their own light. Most students will be familiar with fireflies, and may mention bioluminescence in other species.

   Review the basic concept of chemiluminescence. Students should understand that bioluminescence is a type of chemiluminescence, and should also understand the difference between light produced by these processes and light produced by fluorescence and phosphorescence. The key concept is that every light producing process requires a source of energy (chemical, electrical, mechanical, or light). Students may ask about incandescence, in which light is produced by combustion reactions (thermal energy). Review the concept of the visible and near-visible light spectrum. Students should understand that light at the blue end of the spectrum (including ultraviolet light) has higher energy than light at the red end of the spectrum (including infrared).

3. Tell students that you will demonstrate chemiluminescence, fluorescence, and phosphorescence in a collection of materials. Tell students that they are to keep a record of each material, and decide whether it is an example of chemiluminescence, fluorescence, or phosphorescence. Make your classroom as dark as possible, then begin by snapping two or three different-colored lightsticks (red, yellow, and blue are ideal). Next, use an ultraviolet lamp to illuminate your collection of fluorescent/

phosphorescent materials. Tell students that the ultraviolet lamp is producing light just beyond their range of vision. Because this light is near the blue end of the spectrum, it has higher energy than visible light. Students should record which materials produce light and the color of the light produced. Turn off the ultraviolet light to see whether any of the materials continue to emit light. Students should:

- record the results of each procedure;
- infer whether the procedure is an example of chemiluminescence, fluorescence, and phosphorescence; and
- provide a brief justification for their inference.

If you want to demonstrate triboluminescence, have one or more students bite down hard on a few pieces of wintergreen candy while other students watch carefully for tiny flashes of blue light. Alternatively, you may crush the candy in a pair of pliers.

Demonstrations of bioluminescence are also possible, but will require additional preparation and class time. Sources of information and supplies are provided under "Extensions."

4. Discuss students' inferences. The lightsticks are examples of chemiluminescence. Flexing a lightstick 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 lightstick. 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.

   Objects that produced light only while being irradiated with the ultraviolet lamp are examples of fluorescence. Objects that continued to glow after the ultraviolet lamp was turned off are examples of phosphorescence. Some of these objects may glow before they are exposed to ultraviolet light at all. The explanation for this result is that the objects were exposed to a source of light energy (sunlight, room light, etc.) at some point before the room lights were turned off. Be sure students realize that energy for phosphorescent light always comes from an external light source at some tlme 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.

5. Ask students how these light-producing processes might be useful to organisms living in the deep ocean. Because explorations of deep-sea communities are just beginning, the fact is that we probably don't know all of the ways that these 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. Remind students that their observations of chemiluminescence in lightsticks shows that a variety of colors can be produced by this process and tell them that despite the variety of possible colors, most marine bioluminescence is blue or blue-green. Lead a discussion of possible explanations for this. You may need to remind students that light at the blue end of the spectrum has higher energy than light at the red end of the spectrum. Tell students that most marine organisms only seem to be able to detect blue light.

   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 (so far as we know) cannot see red light, the malacosteids can sneak up on their prey without being detected.

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 be closer to 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 the glowing cloud produced by the worm exposes the threatening invader and makes the invader vulnerable to attact by a higher order predator.

6. Discuss how light-producing processes and the ways they are used by deep-sea organisms could be useful to scientists exploring deep ocean environments. The 2004 Deep-Scope Expedition will use several techniques to make observations that have never been made before. A new deep-sea observatory called Eye-in-the-Sea can be placed on the bottom and left alone to observe sea life without interference from a submersible vessel. The observatory is capable of capturing video images using only red light (which should be invisible to many organisms) and can be programmed to acquire time-lapse images (one minute of recording every 15 minutes) over several days. The video recording system can also be programmed to respond to bioluminescence, so that whenever a bioluminescent event is detected, the recorders will start to capture additional bioluminescent images, then will turn on the red illumination to capture an image of the organism producing the bioluminescence.

   Other observations will use ultraviolet light to search for fluorescent organisms that may be less visible under "white" light. A related study will measure the spectral reflectance of captured organisms, to determine what kinds of illumination will make these organisms most visible to observers. Yet another series of studies will investigate whether polarized light is used by deep-sea organisms, how polarized light is changed by these organisms and deep-sea water, and whether these changes can be detected and recorded.

The BRIDGE Connection

www.vims.edu/BRIDGE/ – Click on "Biology" in the navigation menu to the left, then "Plankton," then "Phytoplankton" for resources on ocean food webs. Click on "Ecology" then "Deep Sea" for resources on deep sea communities.

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

Evaluation

Reports of student observations prepared in Step 3 provide opportunities for assessment.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov to find out more about the 2004 Deep-Scope Expedition and about opportunities for real-time interaction with scientists on current Ocean Exploration expeditions.

2. A more elaborate demonstration of fluorescence using a viscoelastic liquid (see http://sprott.physics.wisc.edu/demobook/chapter6.htm). Viscoelastic liquids consist of molecules containing long chains of atoms. When one of these liquids is poured from one beaker to another, the liquid will continue to pour, even when the upper beaker is held upright. The liquid seems to defy gravity as it continues to run up and over the rim of the upper beaker. If the stream of liquid is cut with a pair of scissors, the upper part of the stream will jump back into the upper beaker. Adding fluorescein to the viscoelastic liquid makes it visible under ultraviolet light and provides an interesting visual effect.

3. To demonstrate fluorescence of chlorophyll, chop 500 grams of spinach leaves into small pieces and put into a 1-liter jar containing 750 ml of rubbing alcohol. Let the jar stand in the freezer for 2-3 days to produce a dark green chlorophyll solution. Shine a flashlight on one side of the jar, and observe dark red fluorescence on the same side.

   This is a demonstration of two paths through which chlorophyll may release captured light energy (photons). One channel is through photosynthesis; the other is through fluorescence. If photosynthesis occurs under optimal environmental conditions, there will be more photosynthesis and less fluorescence. However if the environmental conditions are not optimal (too much radiation, too little nutrients or too much carbon) then there will be more fluorescence and less photosynthesis. See http://www.woodrow.org/teachers/esi/1999/princeton/projects/uv/classroom.html for more details.

4. 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. Fotodyne, Inc. offers kits for demonstrating bacterial bioluminescence (see http://www.fotodyne.com/education/safelumi.php).

Resources

http://www.lifesci.ucsb.edu/~biolum/ — The Bioluminescence Web page

http://www.24hours7days.com/Science/Blacklight_Items.html — Online supplier of a variety of science education supplies, including ultraviolet lamps

http://www.glowspace.com/ – Web site for The GlowSpace Inc., offering various products for demonstrating chemiluminescence

http://www.nightsea.com/ – Web site offering products for studying fluorescence underwater

http://www.flinnsci.com – Web site for Flinn Scientific, Inc., source for materials for demonstrating chemiluminescence. Phone 1-800-452-1261

http://www.biolum.org/ – Harbor Branch Oceanographic Institution Web site on bioluminescence

http://www.sas.upenn.edu/~mtc/Lightstick.html – Information about the chemistry of lightsticks

http://ice.chem.wisc.edu/materials/light/lightandcolor7.html – Web site with links to other activities involving fluorescence and phosphorescence

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

http://oceanica.cofc.edu/activities.htm – Project Oceanica Web site, with a variety of resources on ocean exploration topics

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
- Transfer of energy

Content Standard C: Life Science
- Structure and function in living systems
- Diversity and adaptations of organisms

Content Standard F: Science in Personal and Social Perspectives
- Populations, resources, and environments
- Science and technology in society

For More Information

Paula Keener-Chavis, National Education Coordinator/Marine Biologist
NOAA Office of Exploration
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 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