ocean explorer
oceanexplorer.noaa.gov

2004 Deep-Scope Expedition

Who Has the Light?

Focus
Bioluminescence in deep-sea organisms

Grade Level
7-8 (Life Science)

Focus Question
What deep-sea organisms are capable of bioluminescence, and how does this ability benefit these organisms?

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

Students will be able to explain at least 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
- ❑ None

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

Teaching Time
One 45-minute class period, plus time for student research

Seating Arrangement
Classroom style or groups of 3-4 students

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 research bioluminescence in a variety of marine organisms, and draw inferences on how the ability to produce light may benefit the organisms and how scientists may use light-producing properties for research.

Learning Procedure

1. If you want to include demonstrations of chemiluminescence, bioluminescence, fluorescence, and phosphorescence, see the 'Cool Lights" lesson plan for suggestions. The following web sites are useful resources if you want to show images of deep-sea environments and organisms that use bioluminescence:
   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, and contrast this process with fluorescence and phosphorescence. Students should understand that every light-producing process requires a source of energy (chemical, electrical, mechanical, or light). Tell students that bioluminescence is a form of chemiluminescence that occurs in living organisms, but do not explain the details of bioluminescence at this point. Students may ask about incandescence, in which light 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 their assignment is to investigate light-producing processes in one or more marine organisms, and prepare a report that contains answers to the following questions:
   - What is the basic chemistry of bioluminescence?
   - What color is bioluminescence?
   - How does your organism use bioluminescence?
   - Some animals that are capable of bioluminescence seem to have no use for the light they produce. What are some explanations for this?
   - How does the light output from bioluminescence compare to a 100-watt light bulb?
   - What are some practical uses of bioluminescence?

   As part of their research, challenge students to solve the mystery of the color-changing squid (from http://www.lifesci.ucsb.edu/~biolum/organism/squid.html). Many squids have their lower (ventral) surfaces covered with small light-emitting photophores which put out a soft glow when the squid turns them on. These squids also move vertically through the water each day (vertical migration). They stay down deep during the daylight, but come up to the surface at night under cover of darkness. How are photophores on the ventral surfaces useful to the squid?

Assign one or more of the following organisms to each student or student group:
- Bacteria
- Dinoflagellates
- Cnidaria
- Ctenophores (comb jellies)
- Mollusca
  - Squid
- Annelid worms
  - Polychaetes
- Crustaceans
  - Ostracods
  - Amphipods
  - Decapod shrimp
  - Euphausiids (krill)
- Echinoderms
- Urochordates
- Chordates
  - Sharks
  - Fish
  - Anglerfish
  - Black Dragonfish
  - Malacosteids

4. Have each student or student group present and discuss the results of their research. Points that should emerge during these discussions include:
   - **What is the basic chemistry of bioluminescence?**
     Bioluminescence typically requires a light-emitting organic molecule known as a luciferin, a source of oxygen, and a protein catalyst (enzyme) known as a luciferase. The luciferin receives energy from a chemical reaction catalyzed by the luciferase and using oxygen, then releases the energy in the form of light.

     A few animals, like the angler fish, grow bioluminescent bacteria in their light organs. In this mutualistic symbiotic relationship, the fish supplies bacteria with food and the bacteria provide the fish with light needed to attract prey.
   - What color is bioluminescence?
     Bioluminescence comes in all colors, red, orange, yellow, green, blue and violet, but most marine bioluminescence is blue or blue-green. Light at the blue end of the spectrum has higher energy than light at the red end of the spectrum. Consequently, blue light penetrates farther through seawater than light having longer wavelengths (toward the red end of the spectrum). Most marine organisms only seem to be able to detect blue light.
   - **How may deep-sea organisms use bioluminescence?**
     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. 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 attack by a higher order predator.

It is important for students to realize that since explorations of deep-sea communities are just beginning, we almost certainly don't know all of the ways that these processes are used by deep-sea organisms.

- **Some animals that are capable of bioluminescence seem to have no use for the light they produce. What are some explanations for this?**
  One possibility is that bioluminescence in these animals is a vestigial adaptation that was useful at some point in the animal's evolutionary history, but is no longer useful. But since bioluminescence requires considerable energy, it is unlikely that such an adaptation would persist if it had no survival value. A more likely explanation is that we simply don't know enough (yet) to understand why bioluminescence is useful to these animals.

- **How does the light output from bioluminescence compare to a 100-watt light bulb?**
  One bioluminescent bacterium produces about 1000 to 10,000 (10^3 to 10^4) photons per second, while a single bioluminescent dinoflagellate will emit 10^{10} to 10^{11} photons per second. A 100-watt light bulb emits about 10^{18} photons per second. So you would need 10^7 to 10^8 (ten to one hundred million) dinoflagellates all flashing at once to equal the light output of a single 100-watt bulb. Of course, the light bulb stays lit continuously, while the output of the dinoflagellates is intermittent.

- **What are some practical uses of bioluminescence?**
  Answers may include:
  – Bacterial bioluminescence is used to test for contaminants in food.
  – Chemicals from jellyfish are used in genetic research to allow researchers to see when a gene is activated.
  – Fluorescent proteins from jellyfish are also used to design living systems for the exploration of other planets (see the "Lights in the Deep" lesson plan for more details).

5. 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 fifteen 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 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 about how bioluminescence affects (or might affect) their own lives.

Connections to Other Subjects

English/Language Arts, Earth Science, Physical Science

Evaluation

Written reports 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. 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.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://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