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**Bioluminescence 2009:
Living Light on the Deep Sea Floor Expedition**

Picture This!

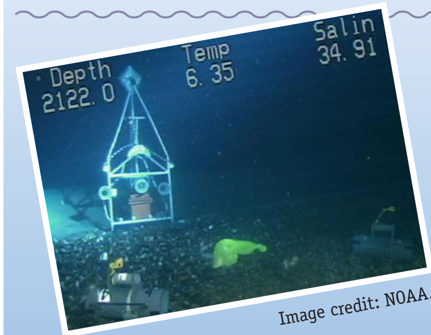


Image credit: NOAA.

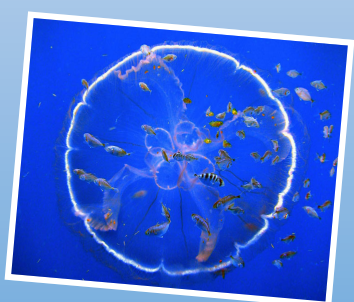


Image credit: NOAA.


Image credit: NOAA.

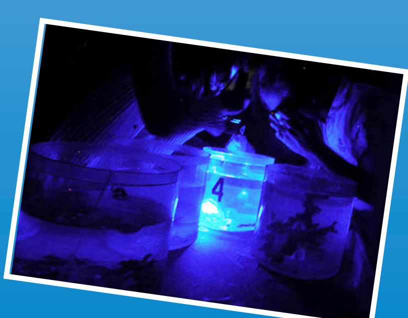


Image credit: NOAA.

Image captions on Page 2.

lesson plan

Focus
Infrared, ultraviolet, and polarization photography

Grade Level
9-12 (Life Science)

Focus Question
How can visible images be produced that show infrared, ultraviolet, and polarization phenomena?

Learning Objectives
- Students will be able to compare and contrast infrared, ultraviolet, and visible light regions of the electromagnetic spectrum.
- Students will be able to explain the meaning of “polarized light,” and will be able to identify three ways in which unpolarized light can become polarized.
- Students will be able to create photographic images that demonstrate infrared, ultraviolet, and polarization phenomena.

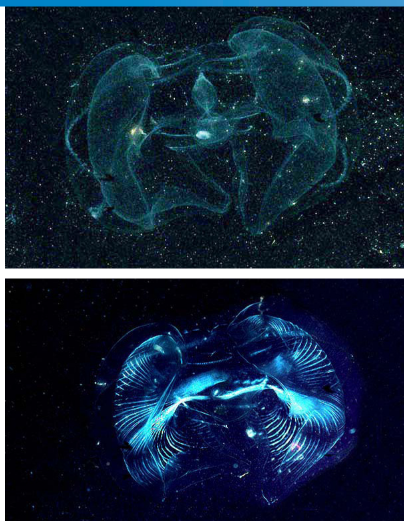
Materials
- The “Infrared, Ultraviolet, and Polarization Photography Inquiry Guide,” one copy for each student group
- Digital cameras (supplied by students)
- Infrared, ultraviolet, and polarizing filters (see Inquiry Guide and Learning Procedure Step 1c)

Audio/Visual Materials
- (Optional) Images showing light and color in deep-sea environments and organisms (see Learning Procedure, Step 1e)

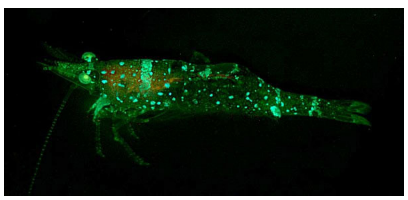
Teaching Time
Two 45-minute class periods, plus time for student inquiry

Seating Arrangement
Groups of 2-4 students

Maximum Number of Students
30



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

Key Words

Light
Vision
Photography
Electromagnetic spectrum
Color
Wavelength

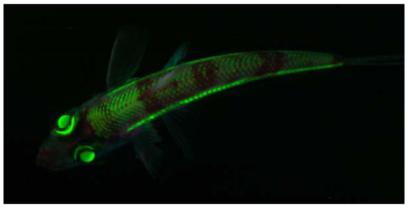
Background Information

[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.*]

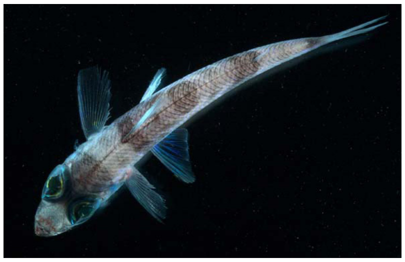
Deep ocean environments are almost completely dark; yet light is still important in these environments. Many marine species are able to produce "living light" through a process known as bioluminescence, but very little is known about specific ways that deep-sea organisms use this ability. Part of the 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.

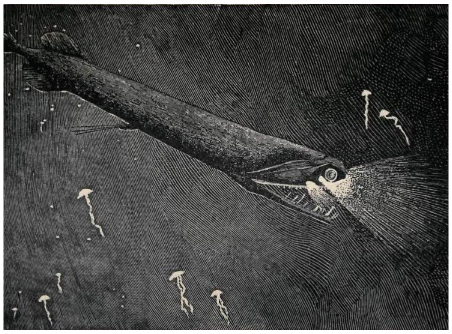
These techniques are based on a number of concepts related to the basic properties of light in seawater, as well as different ways in which certain forms of light may be perceived by living organisms. "Light" is usually defined as the portion of the electromagnetic spectrum that is visible to the normal human eye, but since the Bioluminescence 2009 Expedition is concerned with eyes other than human ones, we need a broader definition. It is helpful to think of light as a series of waves that consist of energy in the form of electric and magnetic fields that together are known as



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.

electromagnetic radiation. These waves can have many different wavelengths (the distance between any two corresponding points on successive waves, such as peak-to-peak or trough-to-trough), so they form a spectrum of wavelengths. The full range of wavelengths in the electromagnetic spectrum extends from gamma rays that have wavelengths on the order of one billionth of a meter, to radio waves whose wavelengths may be several hundred meters. In some light waves, the electric charges that form the waves vibrate in many different directions. These light waves produce unpolarized light. If the electric charges are all vibrating in the same direction, the light is said to be polarized (see the Twisted Vision lesson plan for additional details and discussion).

The wavelength of light visible to humans ranges from about 400 billionths of a meter (400 nm; violet light) to 700 billionths of a meter (700 nm; red light), but we know that some organisms are able to detect light wavelengths outside these limits in the infrared (above 750 nm to about 0.1 mm) as well as ultraviolet (below 400 nm to about 10 nm) regions of the spectrum. During the Operation Deep Scope 2005 Expedition, scientists discovered several species of deep-sea crabs with visual pigments that are sensitive to ultraviolet light. Other expeditions have found that some deep-water fishes known as loosejaws produce bioluminescent light that is nearly infrared. Similarly, humans have a very limited ability to distinguish unpolarized and polarized light, though other species are much more sensitive to polarization and are able to use this ability in a variety of ways. One of the challenges for ocean explorers is to find ways to extend our eyes beyond the normal limits of human vision so that we can begin to see the deep ocean environment as the organisms who live there see it.

Photography provides a valuable tool for extending the limits of human vision, and has been a key element of the 2004 and 2005 Deep Scope expeditions as well as Bioluminescence 2009 (for more information on the Deep Scope expeditions, see essays on Deep Light, Measuring Color, Measuring Vision, Detecting Fluorescence, Polarization Vision, and Eye-in-the-Sea at http://oceanexplorer.noaa.gov/explorations/04deepscope/welcome.html; and Underwater Imaging, Polarization Vision, and Fluorescence at http://oceanexplorer.noaa.gov/explorations/05deepscope/welcome.html). This lesson guides student inquiry into photographic techniques for producing visible images that show infrared, ultraviolet, and polarization phenomena. Note that this lesson is intentionally open-ended. The idea is to provide some tools that will allow students and educators to explore their world with “new eyes;” and just like ocean explorers, there is a strong likelihood that you will see things that you have never seen before!

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), particularly "Seeing in the Dark: Imaging and vision at low light levels."
   b. Review questions and procedures on the "Infrared, Ultraviolet, and Polarization Photography Inquiry Guide," and decide whether you want to assign specific options to student groups or allow students to make their own selection.
   c. Prior to beginning this project, discuss the types of cameras that students have available for their use, particularly the size and mounting system for filters. It will be advantageous to standardize as much as possible so that filters can be shared among several groups. Determine the types of filters that will be required, and obtain these from a supplier of photographic materials. Some comparison Web shopping can save a lot of money on these items, and you may want to have students assist with this aspect of Web research.
   d. Make a copy of the Inquiry Guide for each student group.
   e. 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 Bioluminescence 2009 Expedition. You may want to show images of various deep-sea environments and organisms, and briefly review background information from the introductory essays. Review the concept of the visible and near-visible light spectrum, and the wavelengths of infrared and ultraviolet light. Students should realize that while human eyes cannot detect these wavelengths, many other species are able to do so. Briefly discuss polarized light, again emphasizing that while humans have very limited abilities to detect polarization, this ability is well-developed in other species. Discuss the potential for photography to make infrared, ultraviolet, and polarization phenomena visible. Tell students that their assignment is to use photography to explore and document these phenomena in their own environment.

3. Provide each student group with a copy of the "Infrared, Ultraviolet, and Polarization Photography Inquiry Guide," and review procedures for sharing filters. Remind students that they are

to submit a work plan for approval before beginning their project, and review deadlines for submitting workplans and final reports. Now turn them loose!

4. Have each group present results of their inquiries. In addition to displaying their photographs (some of which are likely to be spectacular!), students should explain the physical basis for their results including:
   - wavelengths of light involved;
   - how and why filters were used;
   - instances of reflected, refracted, and transmitted light; and
   - instances of fluorescence (if any).

   You may also want to have students present their results to other audiences (parents, faculty, or other classes), and/or prepare a scientific poster of their results. See the "Living Light" (Grade level 9-12) lesson for more information about scientific posters.

The BRIDGE Connection

http://www.vims.edu/bridge/archive0305.html – A lesson on fish eyes.

The "Me" Connection

Have students write a short essay on, or discuss as a group, how their perception of their environment might change if humans had well-developed infrared, ultraviolet, and polarization vision, what practical uses this ability might have, and why our species (unlike many others) has not developed these abilities.

Connections to Other Subjects

English/Language Arts, Physical Science, Earth Science

Assessment

Students' reports 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. Visit http://www.exploratorium.edu/snacks/polarized_mosaic/index.html and http://www.exploratorium.edu/snacks/rotating_light/index.html for easy classroom activities involving polarized light.

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 cofactors 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.

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://polarization.com/index-net/index.html – Web site with extensive information on polarized light and how polarization vision is used by various animals.

http://www.lifesci.ucsb.edu/~biolum/ —The Bioluminescence Web Page http://www.wrotniak.net/photo/infrared/ – Web site with extensive discussion and details about infrared photography

http://photonotes.org/articles/ir-myths/ – Popular myths and other information about infrared photography

http://msp.rmit.edu.au/Article_01/06.html – Article about reflected ultraviolet photography

http://www.instructables.com/id/Photography-in-the-Ultraviolet-spectrum/ – "Photography in the ultraviolet spectrum"

http://www.instructables.com/id/Capture-the-Ethereal-Beauty-of-Everyday-Objects-Us/ – "Capture the Ethereal Beauty of Everyday Objects Using Polarized Light".

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 and properties of matter
- Interactions of energy and matter

Content Standard C: Life Science
- Biological evolution
- Interdependence of organisms
- Behavior of organisms

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard G: History and Nature of Science
- Science as a human endeavor

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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For More Information

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Picture This!

Infrared, Ultraviolet, and Polarization Photography Inquiry Guide

Your assignment is to use photography to explore and document infrared, ultraviolet, and polarization phenomena in your environment. There are five steps to complete this assignment:

1. Do background research on infrared, ultraviolet, and polarization photography, and decide how you will use one or more of these techniques to investigate unseen features in your environment.
2. Prepare a workplan for your investigation, and obtain your teacher's approval for the plan.
3. Conduct your investigation.
4. Prepare a report of your results. In addition to your photographs, the report should explain the physical basis for your results including wavelengths of light involved; how and why filters were used; instances of reflected, refracted, and/or transmitted light; and instances of fluorescence (if any).
5. Present your findings.

Background Information

Infrared, ultraviolet, and polarized light are not generally detectable by human eyes. Photography, however, provides a way to use these types of light to make visible images. Often, these images reveal some unexpected features in familiar objects, and sometimes reveal objects and features that we have never seen before! This is possible because the imaging devices used in photography (traditionally film, now electronic sensors) are more sensitive to some wavelengths than our own eyes.

The references below provide details of specific techniques. In general, infrared, ultraviolet, and polarization photography require:

- A photographic sensor capable of detecting the light wavelengths of interest;
- A source of infrared, ultraviolet, or polarized light; and
- A filter to reduce or eliminate unwanted wavelengths (usually visible light that masks the wavelengths of interest).

For example, we could make images with ultraviolet light using a digital camera (many of which are sensitive to ultraviolet light), sunlight as a source of ultraviolet light, and a filter that eliminates wavelengths longer than 400 nm. Because most photographic imaging systems are designed for use with visible, longer-than-normal exposures (several seconds or longer) may be needed to produce a satisfactory image, and this means that a tripod must be used to keep the camera motionless while the exposure is being made.

Picture This!

Infrared, Ultraviolet, and Polarization Photography Inquiry Guide – 2

Polarization photography is a bit different: because it uses light wavelengths within the visible spectrum, almost any photographic imaging systems can be used; but it still requires a source of polarized light and a filter to eliminate light that would obscure our view of polarization effects. The link http://www.instructables.com/id/Capture-the-Ethereal-Beauty-of-Everyday-Objects-Us provides a good example, and an easy way to begin exploring with polarized light.

The following filters are a good start for infrared, ultraviolet, and polarization photography:

- Infrared – Wratten filter #89B or 87C (equivalent to B+W 092 and 093)
- Ultraviolet – B+W filter no. 403
- Polarization – linear polarizing (haze reducing) filters; if you want to use artificial lights (such as floodlights) as a source of polarized light, you can place a large sheet of polarizing material (such as Calumet Photo Catalog Number RC3000; http://www.calumetphoto.com) between the light and the subject being photographed; you can cut a piece of this same material to make a filter for the camera lens as well.

NOTE: Mention of trademarks or proprietary names does not imply endorsement by NOAA.

Web links to start your research (there are many other Web sites and books that also have information on infrared, ultraviolet, and polarization photography):

http://www.wrotniak.net/photo/infrared/ – Web site with extensive discussion and details about infrared photography

http://photonotes.org/articles/ir-myths/ – Popular myths and other information about infrared photography

http://msp.rmit.edu.au/Article_01/06.html – Article about reflected ultraviolet photography

http://www.instructables.com/id/Photography-in-the-Ultraviolet-spectrum/ – "Photography in the ultraviolet spectrum"

http://www.instructables.com/id/Capture-the-Ethereal-Beauty-of-Everyday-Objects-Us/ – "Capture the Ethereal Beauty of Everyday Objects Using Polarized Light"