www.oceanexplorer.noaa.gov

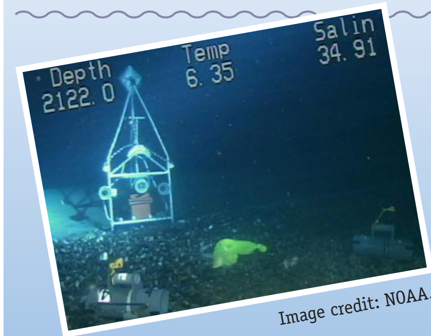


Image credit: NOAA.

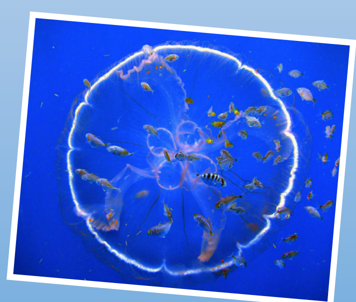


Image credit: NOAA.


Image credit: NOAA.

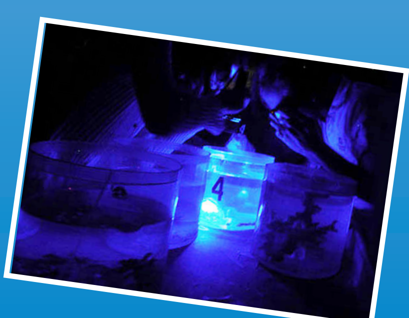


Image credit: NOAA.

Image captions on Page 2.

lesson plan

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

# Twisted Vision

*(adapted from the 2005 Operation Deep Scope Expedition)*

## Focus
Polarization vision

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

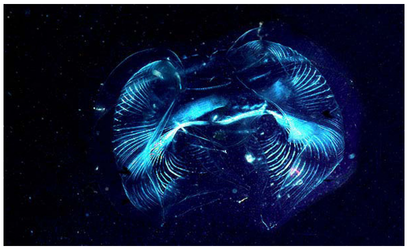
## Focus Question
How do animals use polarized light in the marine environment?

## Learning Objectives
- 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 explain why some animals have polarization vision, and why humans do not have this ability.
- Students will be able to discuss three ways in which polarization vision may be useful to marine organisms.

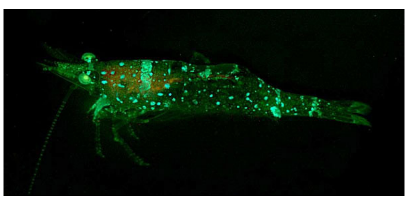
## Materials
- Polarizing filter material (available from many educational supply companies and from Calumet Photo (1-800-225-8638), catalog number RC3000; about $40 for a 17 x 20 inch sheet); two sheets at least 2 in x 2 in for each student or student group
- Plastic objects such as protractors, drafting triangles, and/or clear plastic forks (see Learning Procedure, Step 2); one or two objects for each student or student group
- Copies of "Polarization Vision Inquiry Guide," one copy for each student or student group

## Audio/Visual Materials
- (Optional) Images showing light and color in deep-sea environments and organisms
- (Optional) Overhead projector

## Teaching Time
One or two 45-minute class periods



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

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

## Maximum Number of Students
30

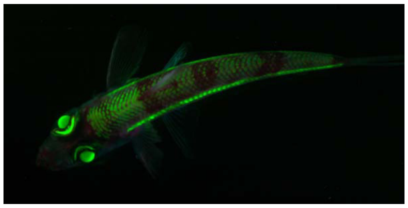
## Key Words
Light
Polarization vision
Electromagnetic spectrum
Dichroic
Birefringence

## 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.*]

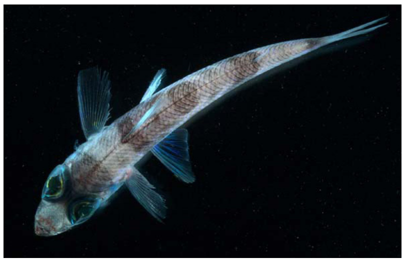
Deep ocean environments are almost completely dark; yet light is still important in these environments. Many marine species are able to produce "living light" through a process known as bioluminescence, but very little is known about specific ways that deep-sea organisms use this ability. Part of the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

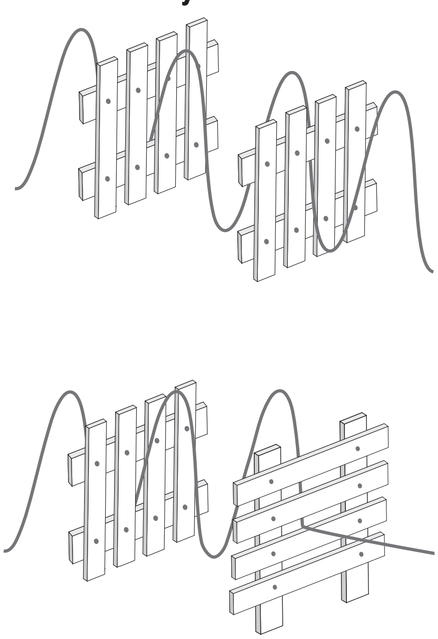


Under white light, the greeneye fish looks very different, but its green lenses are still apparent. Image credit: NOAA. http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug16/media/greeneye_600.jpg

the 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 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. The wavelength of light visible to humans ranges from 400 billionths of a meter (400 nanometers; violet light) to 700 billionths of a meter (700 nanometers; red light), but we know that some organisms are able to detect light wavelengths outside these limits.

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. Most light, including light from the sun, from ordinary light bulbs, and from candles is not polarized. Unpolarized light can be transformed into polarized light in several ways, including transmission, reflection, refraction, and scattering. Polarization by transmission is done by passing light through a filter made of a material that only transmits light waves that are vibrating in a single direction (the polarization axis of the filter); light waves vibrating in other directions are blocked.

**Figure 1:**
**Polarization by Transmission**



A picket fence analogy (Figure 1) is often used to describe polarization by transmission. If we imagine a rope passing through the space between the pickets, it is easy to understand that a wave created by moving one end of the rope could only pass through the fence if the wave were in a plane parallel to the pickets; a wave in any other plane would run into the pickets and be stopped.

The same analogy can be used to explain what happens when light is passed through two polarizing filters. If the polarization axes of the two filters are parallel, then light waves whose direction of vibration is parallel to these axes will pass through the filter; just as a wave in a rope passing through two fences with parallel pickets could pass through both fences as long as the plane of the wave was parallel to the pickets. But if the polarization axes of the two filters are perpendicular to each other, no light will pass through because the polarized light passing through the first filter would be blocked by the second filter; just as a rope wave passing through a picket fence would be blocked by the pickets of a second fence if those pickets were perpendicular to the first fence.

Light can also be polarized by reflection from non-metallic surfaces such as roads, snow, and water. The degree of polarization depends upon the type of surface and the angle at which the light approaches the surface. Glare from these surface can be reduced or eliminated by polarizing filters (such as sunglasses) whose polarization axis is not parallel to the polarization of the reflected light waves. Other mechanisms for polarization include refraction through dichroic materials and scattering (light scattered off of particles in the atmosphere is partially polarized).

At best, humans have a very limited ability to distinguish unpolarized and polarized light. Other species, however, are much more sensitive to polarization, and are able to used this ability in a variety of ways. This lesson guides student inquiry into some of the properties of polarized light and polarization vision.

## Learning Procedure

1. To prepare for this lesson:
   a. Read:
      – Introductory essays for the 2009 Deep Scope Expedition (http://oceanexplorer.noaa.gov/explorations/09deepscope/welcome.html);
      – "Secret Communication Channels in the Ocean: Polarization Vision" (http://oceanexplorer.noaa.gov/explorations/04deepscope/background/polarization/polarization.html);
      – "Hiding in Plain Sight:  Birefringence" (http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug15/aug15.html); and
      – "Measuring Vision in Crustaceans" (http://oceanexplorer.noaa.gov/explorations/04deepscope/background/vision/vision.html)
   b. Review some of the images and video clips from http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/photolog/photolog.html, and http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/photolog/photolog.html.
   c. Assemble materials for each student group listed under "Materials." Note that not all plastic objects will exhibit birefringence, so try your objects before class to make sure they will work!

2. Review the concepts of the visible and near-visible light spectrum, but do not discuss polarized light until Step 4. Briefly discuss the mission plan and activities of the 2004 and 2005 Deep Scope Expeditions. You may want to show images of various deep-sea environments and organisms.

3. Provide each student or student group with a copy of "Polarization Vision Inquiry Guide," and tell students that their assignment is to investigate some of the properties of polarized light and polarization vision. You may want to direct students to the Ocean Explorer Web pages listed above and to http://polarization.com/index-net/index.html, or allow students to locate these resources on their own. A keyword search on "polarization vision" will produce numerous resources adequate for completing the worksheet.

   If time and/or materials are limited, you can do Inquiry Guide Part B as a demonstration. Using an overhead projector makes it easy for everyone to see what's going on.

4. Lead a discussion of students' answers to questions on the worksheet. The following points should be included:

   **Part A**

   1. *Polarized light* consists of light waves that are vibrating in a single direction. You may want to use Figure 1 and the picket fence analogy as part of this discussion.

   2. A *dichroic* material is one that selectively absorbs light rays polarized in one direction and transmits other rays that have a different polarization. The term also is used to describe a material or device that splits a beam of light into separate beams having different wavelengths.

   3. *Birefringence* occurs in materials that refract light at different angles depending upon the polarization of the light. Birefringence occurs in many living tissues, and can make food organisms much more visible to marine animals with polarized vision.

   4. *Rhodopsin* is a group of pigments that act as a photoreceptor in the vision systems of many organisms.

   5. *Ommatidia* are "simple" eyes consisting of a lens, crystalline cone, and visual cells containing rhodopsin.

   6. *Compound eyes*, found in many arthropods, are composed of hundreds (or thousands) of ommatidia. In contrast, the human eye consists of a single lens that focuses an image onto light-sensitive cells in the retina that transmit nerve signal to the brain.

7. In humans, the visual pigment molecules are randomly oriented, but in arthropods (and many other invertebrates) many of these molecules are lined up in the same direction. This alignment makes it possible for these animals to detect polarized light. The pigments that act as photoreceptors in humans are very similar to those found in animals with polarization vision. The key difference is the alignment of pigment molecules.

8. Karl von Frisch discovered that bees communicate by "dancing" in a specific pattern. Direction is expressed relative to the current position of the sun, which the bees detect from patterns of polarized light in the sky. For more information, visit http://polarization.com/bees/bees.html.

9. Polarized vision has been found in a wide range of animals, including shrimps, fishes, cephalopods, cnidarians, and annelids.

10. Possible uses of polarized vision include direction finding, communication, "camouflage breaking," and contrast enhancement (which could be useful for seeing potential food species, and well as for avoiding potential predators).

11. *Haidinger's brush* is a diffuse pattern resulting from polarized light that can be seen by many people (who thus are capable of a limited form of polarized vision). Typically, the pattern appears as a fuzzy yellowish horizontal bar or bow-tie shape that is visible in the center of the visual field when the blue sky is viewed while facing away from the sun, or on a bright background while looking through polarized sunglasses. For more information, visit http://polarization.com/haidinger/haidinger.html.

**Part B.**

1. When students look through one sheet of polarizing filter material, they should observe that some of the light (the waves that are not parallel to the polarization axis of the filter) is absorbed.

2. When a second polarizing filter is placed on top of the first and rotated, they should observe that light transmission is maximized when the rotating filter is in one position (where the polarization axes of the two filters are aligned), but that progressively less light is transmitted as the moving filter continues to rotate to a minimum when the moving filter's position is at 90° to the position of maximum transmission (where the polarization axes of the two filters are perpendicular).

3. When the plastic object is placed between two sheets of polarizing filter material, bands of color will appear and move over the surface of the plastic object. Flexing the object may reveal stress lines in the material.

**Part C**

Discuss students' explanations for their observations. Add to their explanations as necessary to be sure the concept of polarized light is fully understood. Point out that the second filter in these demonstrations would not be necessary if human eyes were able to detect polarized light, and we would see many things that are not ordinarily visible to our eyes. Be sure students understand that while humans lack this ability, many other species have well-developed polarization vision.

## The BRIDGE Connection

http://www.vims.edu/bridge/archive0305.html – Activity on vision in pelagic fishes

## The "Me" Connection

Have students (individually or in groups) prepare a presentation describing how their perception of their environment might change if humans had well-developed polarization vision, and what practical uses this ability might have.

## Connections to Other Subjects

English/Language Arts

## 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. Visit http://www.exploratorium.edu/snacks/snacksbysubject.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 Lesson Plans from NOAA's Ocean Exploration and Research Program

**Who Has the Light?**
(7 pages, 200Kb) (from the 2004 Deep Scope Expedition)
http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/WhoHasLight.pdf

Focus: Bioluminescence in deep-sea organisms

In this activity, students compare and contrast chemiluminescence, bioluminescence, fluorescence, and phosphorescence. Students also explain at least three ways in which the ability to produce light may be useful to deep-sea organisms and explain how scientists may be able to use light-producing processes in deep-sea organisms to obtain new observations of these organisms.

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

von Frisch, K. 1967. The Dance Language and Orientation of Bees. Harvard University Press. Cambridge.

Cronin, T. W., N. Shashar, R. L. Caldwell, J. Marshall, A. G. Cheroske, and T.H. Chiou. 2003 . Polarization Signals in the Marine Environment. Proceedings of SPIE 5158:85-92.

## 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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## For More Information

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## Acknowledgements

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## Twisted Vision

# Polarization Vision Inquiry Guide

### A. Web Inquiry

1. What is polarized light?

2. What does "dichroic" mean as it applies to polarized light? [Caution: this term has two meanings in the field of optics; be sure your answer relates to polarized light!]

3. What is "birefringence?" How can marine animals with polarized vision take advantage of birefringence to help capture food?

4. What is "rhodopsin?"

5. What are "ommatidia?"

6. What is a "compound eye" and how does it differ from human eyes?

7. Why do many invertebrates possess polarized vision while humans do not?

8. In 1944, Karl von Frisch discovered that honey bees communicate information about the location of nectar-bearing plants, including the direction of these plants from their hive. How is this communication done? Since bees do not have compasses, how do they detect direction?

9. What are three groups of marine animals known to possess polarized vision?

10. What are three possible uses of polarized vision in marine animals?

## Twisted Vision

# Polarization Vision Inquiry Guide - continued

11. What is "Haidinger's Brush?"

## B. Explore and Observe

1. Look through one sheet of polarizing filter material at a bright light or daylit window. What do you observe?

2. Place a second polarizing filter on top of the first sheet and look through the two sheets at a bright light or daylit window. Now hold one sheet still, and slowly rotate the other sheet. What do you observe?

3. Place a plastic protractor, drafting triangle, or clear plastic fork between two sheets of polarizing filter material and look at a bright light or daylit window through the stack. Rotate one filter. What do you observe?

4. Hold the filters and plastic object together, look at a bright light or daylit window through the stack, and gently flex the plastic object. What do you observe?

## C. Analyze

1. How do you explain your observations in Part B?