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2005 Operation Deep Scope Expedition

Twisted Vision

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
- ❒ Two sheets of polarizing filter material (available from many educational supply companies and from Calumet Photo (1-800-225-8638), catalog number RC3000; about $40 for a 19 in x 20 in sheet)
- ❒ Plastic protractor, drafting triangle, and/or clear plastic fork (see Learning Procedure, Step 2)
- ❒ Copies of "Polarization Vision Worksheet," 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

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
In the deep ocean, even the simplest tasks can become surprisingly complex. One of the primary objectives of ocean exploration is to observe living organisms in deep-sea environments. The near-total darkness of these environments poses an obvious obstacle to such observations, but it would seem relatively easy to overcome this obstacle with artificial lights. Turning on the bright lights carried on deep-diving submersibles, however, creates other problems: mobile organisms often move away from the light; organisms with light-sensitive organs may be permanently

blinded by intense illumination; even sedentary organisms may shrink away and possibly become less noticeable. Even with strong lights, transparent and camouflaged organisms may be virtually invisible, and small cryptic creatures may simply go unnoticed. In addition, some aspects of deep-sea biology such as production of light by living organisms (bioluminescence) can't be studied under ordinary visible light. (For more information and lesson plans about bioluminescence, visit http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/edu.html.)

The 2005 Ocean Exploration Deep Scope Expedition is dedicated to the concept of "seeing with new eyes." Using advanced optical techniques, scientists will be able to observe deep-sea animals under extremely dim light, as well as under different types of illumination that may reveal organisms 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 portion of the electromagnetic spectrum that is visible to the normal human eye. Since the Deep Scope Expedition is concerned with other eyes in addition to human ones, 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 (violet light) to 700 billionths of a meter (red light).

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.

A picket fence analogy 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 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 surfaces 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 acutely sensitive to polarization, and are able to used this sensitivity in a variety of ways. One of the major objectives of the 2005 Deep Scope Expedition is to determine the role of polarized light reception among animals in the pelagic environment. In this lesson, students will explore some of the properties of polarized light and polarization vision.

Learning Procedure

1. To prepare for this lesson:
   - Read:
     – Introductory essays for the 2005 Deep Scope Expedition (http://oceanexplorer.noaa.gov/explorations/05deepscope/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)
   - Review some of the images and video clips from http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/photolog/photolog.html.
2. Review the concepts of the visible and near-visible light spectrum, and of polarized light. Reinforce this review with some simple demonstrations using polarizing filter material. Doing these demonstrations on an overhead projector makes it easy for everyone to see what is going on.
   - Shine a light through a single sheet of polarizing filter material to demonstrate that some of the light (the waves that are not parallel to the polarization axis of the filter) is absorbed.
   - Place a second polarizing filter on top of the first sheet and shine a light through the combined filter. When the second filter is rotated, students will see that the light transmission is maximized when the polarization axes of the filters are parallel. Progressively less light is transmitted as the angle between the polarization axes increases, to a point at which virtually no light is transmitted when the axes are perpendicular.
   - Place a plastic protractor, drafting triangle, or clear plastic fork between two sheets of polarizing filter material and shine a light through the stack. When one filter is rotated, bands of color will appear and move over the surface of the plastic object. At this point, don't tell students that this is an example of birefringence. Flexing the object may reveal stress lines in the material. [Note: Not all plastic objects will exhibit birefringence, so try this before class to make sure your objects will work!]
3. Point out that the second filter in these demonstrations would not be necessary if human eyes were able to detect polarized light, and that while humans lack this ability, many other species have well-developed polarization vision. 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.

Provide each student or student group with a copy of "Polarization Vision Worksheet," 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.

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

   - 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.

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

   - The human eye consists of a single lens that focuses an image onto light-sensitive cells in the retina that transmit nerve signals to the brain. Compound eyes, found in many arthropods, are composed of hundreds (or thousands) of "simpler" eyes called ommatidia. Each ommatidium has a lens, crystalline cone, and visual cells containing rhodopsin. In vertebrates, 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.

   - 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.

   - Polarized vision has been found in a wide range of animals, including fishes, cephalopods, shrimps and many other crustaceans.

   - 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).

   - 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.

The Bridge Connection

http://www.vims.edu/bridge/archive0305.html

The "Me" Connection

Have students write a short essay 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

Evaluation

Students' answers to worksheet questions and class discussions provide opportunities for assessment.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov/explorations.05deepscope/welcome.html to keep up to date with the latest discoveries by the 2005 Deep Scope Expedition.

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

Resources

http://oceanexplorer.noaa.gov/explorations.05deepscope/welcome.html – The 2005 Deep Scope 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://ice.chem.wisc.edu/materials/light/lightandcolor7.html – Web site with links to 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

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, 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

For More Information

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Polarization Vision Worksheet

1. 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!]

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

3. What is "rhodopsin?"

4. What are "ommatidia?"

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

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

7. 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?

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

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

10. What is "Haidinger's Brush?"