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## 2005 Operation Deep Scope Expedition

# The Eyes Have It!

### Focus
Vision in crustaceans

### Grade Level
9-12 (Life Science)

### Focus Question
Why do many crustaceans have visual capabilities that exceed those of humans?

### Learning Objectives
Students will be able to describe the overall structure of the crustacean compound eye.

Students will be able to describe the eyes of stomatopods, and list three of their visual capabilities.

Students will be able to explain why most vertebrates are unable to detect polarized light, while this ability is more common among some invertebrate groups.

Students will be able to discuss three ways in which animals may benefit from polarization vision.

### Materials
❒ Copies of "Crustacean 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

### Teaching Time
One or two 45-minute class periods, plus time for student research

### 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
Vision
Compound eye
Stomatopod
Polarization vision

### 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. One of the practical reasons for these studies is that knowledge of complex vision systems different than our own can provide ideas for new optical systems that may reveal aspects of our world that have previously been undetected. A key objective of the 2005 Deep Scope Expedition is to examine the visual physiology of deep-sea invertebrates. In this lesson, students will examine some of the properties of invertebrate eyes, and how these properties provide much more extensive visual abilities than those of humans.

## 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. Briefly review the concepts of the visible and near-visible light spectrum, wavelength, and polarized light. 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. Tell students that many of these organisms have visual capabilities that are very different from our own, and that their assignment is to investigate the structure and properties of some of the eyes that provide these capabilities. Provide each student or student group with a copy of "Crustacean Vision Worksheet."

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

   - Compound eyes are composed of hundreds (or thousands) of "simpler" eyes called ommatidia (singular = ommatidium). The ommatidia are covered on the outside by a transparent cornea, beneath which are crystalline cone cells. The cornea and cone cells focus light onto an area known as the retinula which contains retinal cells that are capable of sensing light. The light-sensing portion of each retinal cell is called the rhabdomere and contains photopigment that provides the light-sensing capability. The light-sensing region of each ommatidium formed by the rhabdomeres of the retinal cells is called the rhabdom. The rhabdom of each ommatidium is protected from scattered light from adjacent ommatidia by cells containing screening pigments. Nerve structures called axons lead away from the retinal cells and carry signals to the brain that are interpreted as "vision."

- Changes that may make compound eyes more sensitive to light include:
  – Screening pigments may be withdrawn, allowing more light to reach the rhabdom;
  – The volume of the rhabdom may increase substantially; and
  – A reflecting surface (the tapetum) may be exposed at the back of the eye so light waves that pass through the retina without being absorbed are reflected back for a second try.

- Stomatopod compound eyes have six parallel rows of ommatidia arranged around the equator of the eye (like a tire tread). These six rows are called the "midband" region. The portions of the eye above and below the midband are called the dorsal and ventral hemispheres. A single object can be seen by individual ommatidia in each of these three regions. This means that a single stomatopod eye has trinocular vision, and consequently, depth perception (humans require two eyes to achieve depth perception through binocular vision). The top four rows of ommatidia contain eight different classes of visual pigments that respond to different wavelengths of light, including the entire color spectrum visible to humans as well as ultraviolet light. The two bottom rows of ommatidia are specialized for detecting light polarization. Stomatopod eyes are mounted on mobile stalks and can move independently of each other. Eye motion may be slow, scanning movements or very rapid movements that allow the shrimp's gaze to be re-directed without blurring the visual image.

- In vertebrates, the visual pigment molecules are randomly oriented, but in animals with polarization vision many of these molecules are lined up in the same direction. This alignment makes it possible for these animals to detect polarized light.

- Polarized vision may be used by animals to:
  – Orient and navigate between different locations;
  – Enhance the visibility of transparent or well-camouflaged animals that may be potential food (or predators); and
  – For signalling (communication) between members of the same species.

- Bioluminescence produces light in the deep ocean, and may be the major visual stimulus in this environment. In the Frank and Case (1988) study, the ability to detect light in the near-ultraviolet range may be related to bioluminescence of prey species or to bioluminescent signalling between shrimps of the same species. The latter possibility is supported by the fact that that four shrimp species able to detect near-ultraviolet wavelengths also possessed photophores capable of producing bioluminescence. The other four species that did not have 400 nm-sensitive pigments did not have photophores.

## The Bridge Connection

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

## The "Me" Connection

Have students write a short essay describing how knowledge of the structure of invertebrate eyes could be a model for developing technology (reverse engineering) that would be of personal benefit.

## Connections to Other Subjects

English/Language Arts, Physical Science

## Evaluation

Student worksheet assignments 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.woodrow.org/teachers/esi/1999/princeton/projects/uv/classroom.html, http://siobiolum.ucsd.edu/Biolum_demos.html, http://www.lifesci.ucsb.edu/~biolum/organism/dinohome.html, and http://www.fotodyne.com/education/safelumi.php for activities involving fluorescence and bioluminescence.

## 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.

Meyer-Rochow, V. B. 2001. The Crustacean Eye: Dark/Light Adaptation, Polarization Sensitivity, Flicker Fusion Frequency, and Photoreceptor Damage. Zoological Science 18:1175-1197.

Frank, T. and J. F,. Case. 1988. Visual Spectral Sensitivities of Bioluminescent Deep-sea Crustaceans. Biological Bulletin 175:261-273

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

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

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

## 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
- Chemical reactions

**Content Standard C: Life Science**
- The cell
- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

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

**Content Standard F: Science in Personal and Social Perspectives**
- Natural resources
- Science and technology in local, national, and global challenges

**Content Standard G: History and Nature of Science**
- Nature of scientific knowledge

## For More Information

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## Crustacean Vision Worksheet

1. Many crustaceans have compound eyes. Describe the overall structure of the crustacean compound eye. Include an explanation of the following structures: ommatidium, cornea, crystalline cone cell, retinula, retinal cell, rhabdomere, photopigment, screening pigment, and axon.

2. What are three changes that may take place in compound eyes that make these eyes more sensitive to light?

3. The compound eyes of stomatopods (mantis shrimps) have more than ten different classes of visual pigments (humans have three) that provide these animals with complex visual abilities. Describe the eyes of stomatopods, and list three of their visual capabilities.

4. Vertebrates are typically unable to detect polarized light, while this ability (known as "polarization vision") is much more common among invertebrates. The photopigments in the eyes of vertebrates, however, are almost identical to the photopigments in the eyes of invertebrates that have polarization vision. What is different about invertebrate eyes that allow polarization vision?

5. What are three ways in which animals may benefit from polarization vision?

6. Frank and Case (1988) studied visual pigments in eight species of deep-sea shrimps. Four of these species had pigments that were sensitive to light in the 490 - 510 nm wavelength range, which corresponds to blue-green light and is typical of many deep-sea organisms. The other four species had two types of pigments: one group that was sensitive to wavelengths of 500 nm, and another that was sensitive to wavelengths of 400 nm. The latter wavelength is deep violet, nearly ultraviolet. But ultraviolet and near-ultraviolet light are virtually absent in the deep ocean. How could the ability to detect near-ultraviolet light be useful to these shrimps?