Teachable Optics

[Absorption, Scattering and the Color of the Ocean]

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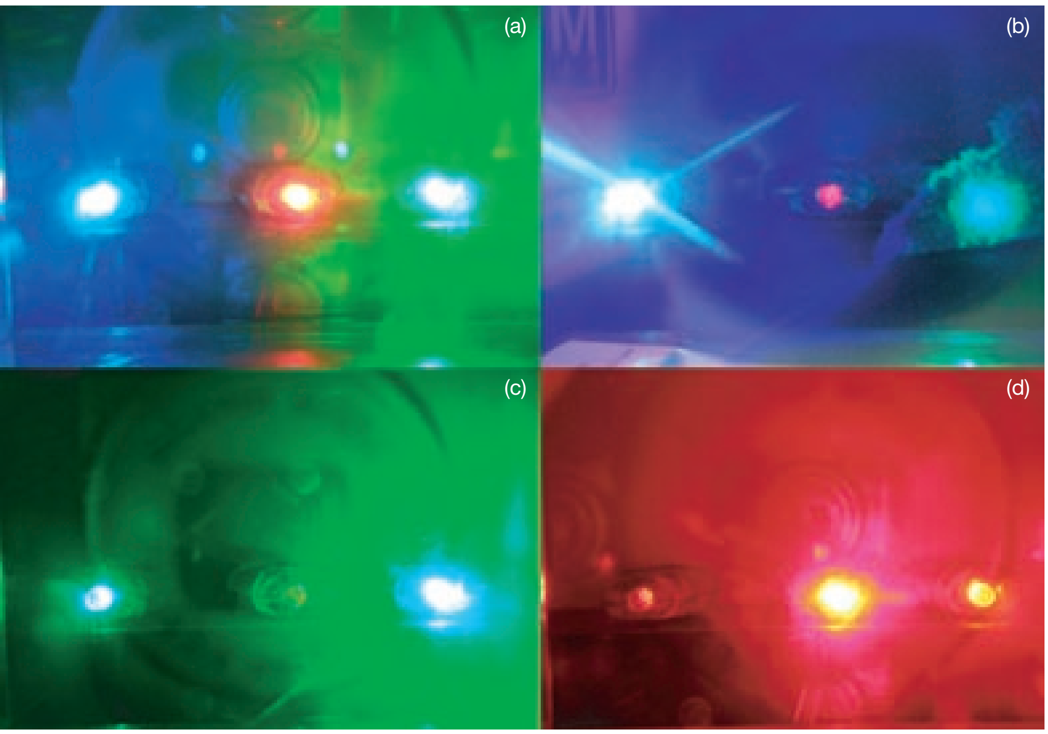
As an optical oceanographer, I study the interaction of light with ocean water to learn more about materials in the water column. Throughout my career, I have had the opportunity to teach the principles of optics to students at many levels, spanning from kindergarteners to graduate students. I would like to share a series of simple activities that I have used with all levels of learners to introduce the concepts of absorption and scattering and how they affect our perception of the environment.

[What You'll Need]

- ✓ 3 colored LEDs (e.g., light-up key chains from a hardware store)
- ✓ 1 laser pointer
- ✓ 4 clear plastic glasses
- ✓ Food coloring – 3 colors
- ✓ Maalox (or milk)
- ✓ Colored paper
- ✓ Printout of a "true color" satellite ocean color image (see, for example, images and resources at: http://oceancolor.gsfc.nasa.gov/SeaWiFS/TEACHERS/).



[Light by three LEDs (blue, red and green) shone through a clear plastic vessel including (a) water, (b) water with several drops of blue food coloring, (c) water with several drops of green food coloring and (d) water with several drops of red food coloring. Notice how the transmission of light is modulated by the color of the medium. The color observed matches the wavelengths that are preferentially transmitted (i.e., least absorbed).]

Demonstrations: What determines the color we observe?

>> Ask students to observe a piece of colored paper and ask them what color it is.

Shine the three LEDs on the paper and ask them again what color they see. Then ask students about the color of the walls in their rooms at home and how it changes when the light is turned off at night.

[CONCLUSION] The color we perceive depends on the color of the illumination as well as the properties of the material observed (in this case, paper).

>> Fill four clear plastic glasses with water. Place several drops of different shades of food coloring (blue, green, red) into three of them and mix.

Shine the three colored LEDs through the glass with no color and ask the students if they can see all of them. Once they do, ask them which color LED will transmit best through the glass with the red food coloring (answer: the red).

Do the same with the other colors. (See figure at left.)

[CONCLUSION] The color we perceive depends on the properties of the medium. In particular, the color we observe is that which is not absorbed by the medium.

>> Next, shine a laser pointer at the wall or ceiling.

Ask the students if they can observe the beam (answer: no). Can they spot the place where the beam hits the wall? How

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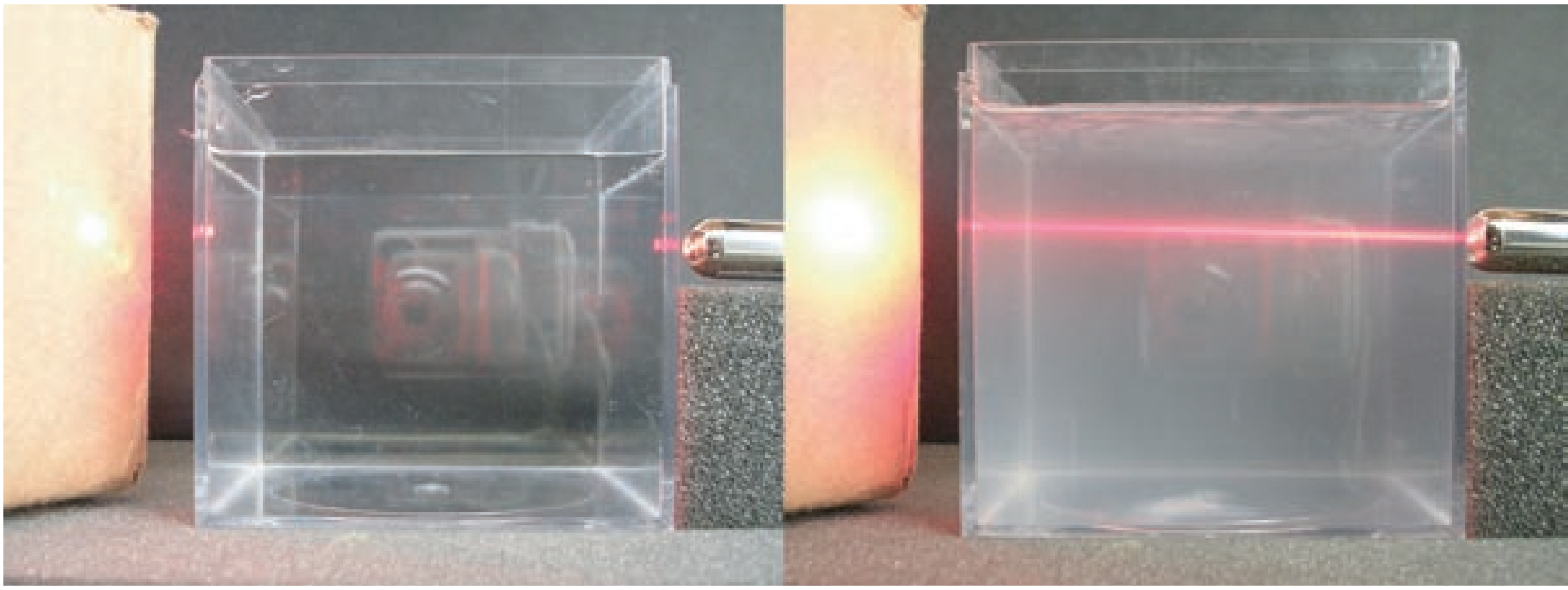

Laser pointer shone through a clear plastic vessel including (a) water and (b) water with several drops of Maalox. The beam is not observed in clear water due to little redirection of photons to our eyes while it is well observed when the water is turbid.

do their observations comport with what they see in science fiction movies, where bright beams often emanate from ray guns or UFOs (answer: movies are not always faithful to reality).

>> Now shine the laser through water (a long aquarium is best).

Can the students observe the beam? (They should not, unless the water is turbid or has many bubbles, or the laser is intense enough that molecular scattering is observable.) Add a few drops of Maalox to the water and mix. Can they observe the beam now? (Answer: yes, see figure above.)

[CONCLUSION] The light we perceive depends on the properties of the medium. In particular, the intensity depends on the scattering of light by the medium.

>> Add a few drops of Maalox to the colored water used earlier.

How does the color change? (Answer: it becomes more intense.)

>> In a clear glass of water, mix all the colors of food coloring.

What is the color observed? (Answer: black.) What does it mean? (Answer: No light is coming out of the cup; all the light ends up within it.) Now add Maalox. How does the color change? (Answer: it lightens up and looks brown, like adding milk into coffee.)

[CONCLUSION] The light and color we perceive depends on the properties of the medium. When we add milk to coffee, we don't change its color (spectra) but rather the amount of light coming back from the glass to our eyes.

Both scattering and absorption can affect color. Scattering by particles much larger then the wavelength affects the intensity of the scattered light but not its color (as demonstrated in the experiment with the Maalox). However, when scattering occurs from particles much smaller than light, it leads to changes in the color of the scattered light compared to the incident light. An example is the color of the sky; because scattering of light by small particles is inversely dependent on wavelength (it decreases as the inverse fourth power of wavelength), short-wavelength blue photons are scattered with higher probability than the longer wavelength red ones. Thus we observe a blue sky.

>> Show participants "true color" images of the ocean taken from satellites such as NASA's SeaWIFS.

Discuss the colors observed (green near the coast and at the equator, blue in the middle of the subtropical gyres). What may cause the variations in color? (Answer: tiny micron-sized algae called phytoplankton absorb blue and red photons near the coasts and equatorial zones, leaving only green photons to scatter back.)

Following these demonstrations, let the students experiment on their own with water, colors and light sources. They are likely to discover some phenomena you did not have time to discuss—for example, total internal reflection at the boundary between water and air, Snell's law, etc.

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[References and Resources]

>> For other hands-on demonstrations in the geosciences, take a look at Zbigniew Sorbjan's book, *Hands-on Meteorology: Stories, Theories, and Simple Experiments* (published in 1996 by the American Meteorological Society).