Sweetness and Light

A Great Lakes Supplement Activity

Teaser: A diver working at a depth of 33 feet (10 meters) cuts his leg on a sharp rock. As he looks down at his leg he sees blood flowing from the wound. What color is the blood he sees?

Summary: Students work in teams to discover which colors (wavelengths) of visible light penetrate furthest into local waters.

Objectives: Students will:

- describe and investigate the properties of light as they interact with water molecules in natural water bodies (Wisconsin Academic Standards, Science, Physical Science, D.8.8).
- conduct an investigation which provides reliable data on the penetration of light energy into water (Science, Inquiry, C.8.3).
- explain the results of the investigation using computer software and other technology to organize and process the results and to present data and conclusions (Science, Inquiry, C.8.7 and C.8.8).

Materials: M & Ms – peanut (assorted colors)
Stopwatch
Data sheet for recording
Graph paper

Making Connections:
Students know that, in addition to the sky, many lakes and the oceans are blue or blue-green in color, but they may not know how light and water interact to create this appearance.

Background:
Like green plants growing on land, algae and other water plants need light in order to grow. They capture light energy from the sun and store some of this energy through the process of photosynthesis.

Light energy of many wavelengths arrives from the sun at the earth all the time. Some of these wavelengths are visible to our eyes, and some are not. All of the visible wavelengths taken together make up white light. But with a prism we can break the white light into a spectrum of colors – violet, blue, green, yellow, orange and red. A material that reflects all of the colors of sunlight back to our eyes appears white. One that absorbs all of the light, and so reflects none back, appears black. Materials that reflect only certain wavelengths and absorb others appear to be the color of the light they are reflecting. Since blood appears to our eyes to be red, it must reflect the red portion of the spectrum and absorb all of the other parts.

Light coming from the sun to earth first reaches the blanket of atmosphere around the planet before it reaches the surface of the earth. Water vapor and other materials in the atmosphere absorb some wavelengths of light better than others. So the sunlight that reaches the surface has already had some wavelengths of visible light reduced. The wavelengths that are reduced most are at both ends of the visible spectrum – violet and red. There is more blue, green and yellow light that reaches the earth's surface, than the other colors.

Once it enters the water, the visible light is rapidly weakened still further by scattering and absorption. Light is scattered as it bounces between air and water molecules, dust particles, algae cells and other materials in the water. Light is also absorbed by water molecules and particles in the water. As the light is absorbed, the light energy is converted to heat and other forms of energy. Water absorbs light more quickly than the atmosphere. Only 45% of the light energy that strikes the water's surface reaches a depth of one meter, only about 15% reaches ten meters and at a depth of 100 meters only about 1 % of the light present at the surface is left.

Again, water molecules absorb some parts of the visible spectrum better than others, so some colors - or wavelengths - travel deeper into the water than others before being completely absorbed. As in the atmosphere, the red and violet wavelengths are absorbed most quickly, followed by the orange and then the yellow. So, as one goes deeper into clear water, there is less light overall and most of that light is in the blue and green wavelengths. One of the reasons that oceans and lakes can appear blue or green is because those wavelengths of light are abundant and can travel far enough through the water – both in and back out – to be scattered back above the surface, reaching our eyes.

Because the character of the light changes as it travels deeper into the water, colors of objects in the water also change. For example, the diver working at 10 meters who cuts his leg does not see red blood. There is not enough red light left at that depth to reflect back to his eyes. Since the other colors are absorbed or transmitted by the blood, he sees the blood as gray. If his blood were blue or green, there would be enough of those wavelengths to reflect to his eyes and the blood would look blue or green.

The wavelengths of light penetrating the water furthest depend on a number of factors including the natural color of the water (tannins will color the water brown, for example), as well as the kind and quantity of living and non-living things suspended in the water. In clear water the blue and green wavelengths are likely to penetrate furthest. In highly colored water, and especially in water with a great deal of suspended sediment or algae, the wavelengths penetrating furthest may be shifted toward the yellow, orange and red.

A Secchi disk provides an indication of how far light penetrates into the water. Light is important as a source of energy for plant growth, and the depth to which sufficient light penetrates is the area where plants can accomplish photosynthesis - the photic zone. This is where the food web starts, with plants capturing the energy and providing the first step in feeding the remainder of the ecosystem. So knowing how far light penetrates is important. In many bodies of fresh water, the depth to which a Secchi disk can be seen - the Secchi depth - represents about one-third of the depth of the photic zone.

In addition to knowing how far light penetrates, we have seen that not all colors travel equally deep in the water. Chlorophyll, the primary plant pigment associated with photosynthesis, absorbs certain wavelengths of light most efficiently. Those colors are in the orange and blue-violet wavelengths, and are generally not available within a few meters of the surface. Many plants that live somewhat deeper in the photic zone have additional pigments that are better at absorbing light that is blue and green, since these are the wavelengths of light that penetrate further. Often, these pigments are reddish-orange in color, reflecting those wavelengths (which are not usually present anyway), and absorbing the remaining wavelengths - the blues and greens. This provides an advantage over those plants that only have the chlorophyll pigments.

Scientists use sophisticated and expensive instruments to measure the quantity and quality of light that reaches down through the water column in lakes and oceans. But the Secchi disk provides an easy way to measure how far light penetrates (the relative quantity) and this activity provides a simple way of determining how far the various colors of light penetrate (the relative quality).

Procedure

Warm Up

Ask the students to describe the visible spectrum. What are the colors that make it up and in what order? Which have the most energy? The least? Older students can find the actual wavelengths of the visible spectrum and the wavelength ranges of the principal colors. Younger students can be asked to bring in examples of pictures etc, which show a spectrum or a portion of a spectrum.

*The Activity**

1) Identify one or more locations where students can drop colored objects directly into the water, with sufficient water depth that the colored objects will disappear from the sight of the student observers as they peer down into the water. Bridges, piers and boats are possible locations for this exercise.

2) Form teams of four students. Each team should have one person to drop the colored objects, one to time the trial, one to observe the disappearance of the object and a fourth to record the results. Combine several tasks if teams are smaller.

3) Each team receives a supply of peanut M&Ms as the colored objects. Since replicate trials are desirable each team should have sufficient candy pieces to test all of the available colors (blue, green, yellow, orange, red and brown) three or four times at each station. Each team should also have a stopwatch or other means of timing and a recording sheet for the data.

NOTE: Peanut M&Ms have been found to be the most suitable object for this test, since they are easily available, biodegradable, fall at an appropriate rate, and are relatively colorfast through the length of the trial. They are also consistent enough in size to assume they all fall at the same rate, and any left over test objects can be eaten by the students at the conclusion of the day's testing.

4) The student dropping the M&Ms holds the colored piece of candy above, and out over, the water with the arm extended straight out from the shoulder. The student timer gives the first student a signal to drop the candy piece and starts timing at the same time. The student observer watches the candy fall through the water until it disappears from sight, and immediately gives a signal to the timer to stop the watch. The student recording the results notes the color of the candy and the time of travel in seconds. This process is repeated until all six of the colors have been tested once at a station. The process is then repeated several more times with additional sets of six M&Ms for each trial. Three to four trials are recommended at each location by each group. Students may rotate assignments within the group from trial to trial – that is, the student who dropped the first set of six colors can become the timer, observer or recorder for the next set of trials, with others rotating jobs as well. The colored pieces can be dropped in any order during a trial, and the order does not need to be the same from trial to trial or group to group.

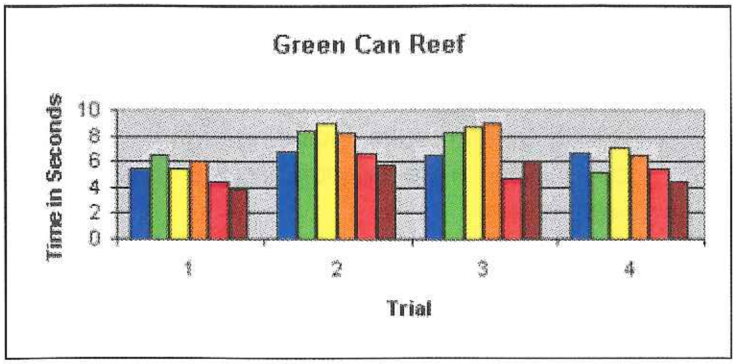
NOTE: Since the intensity of the sunlight (time of day, cloud cover, season, etc.) affects the penetration of light into the water, and the visibility of the candy pieces, this experimental procedure should be done on the shaded side of any structure such as a bridge, boat or pier, where practical.

5) After all results are in, each group of students should average the results for each color at a given station. Average values should be graphed by each group, with colors arranged along the x-axis in the following order – blue, green, yellow, orange, red, brown. Time in seconds should be listed along the y-axis.

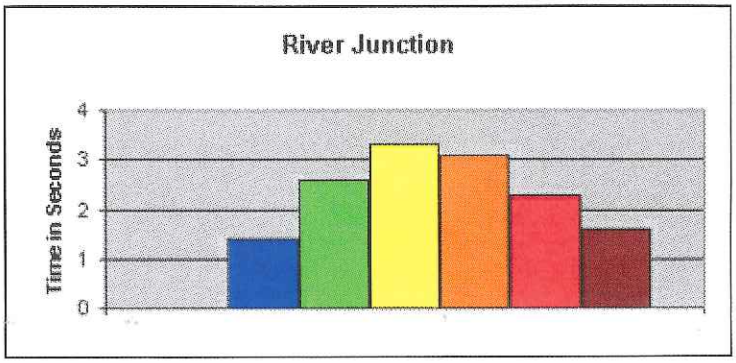
Several examples of data are shown in the graphs below. The data from the Milwaukee area were collected by students using the procedure outlined above. Four trials were done on different cruises at the Green Can reef, located approximately 1.5 miles offshore east of the boundary between Milwaukee and St. Francis. The site listed as the river junction is located at the confluence of the Milwaukee, Menomonee and Kinnickinnic Rivers, just south of downtown Milwaukee. The data listed as "ideal ocean" are based on trials done in the waters over the Puerto Rico trench in October, 1999, but the numbers given are not actual results. They have been generated to represent what light and color would be like under ideal conditions.

Under optimal conditions the light in the blue and green wavelengths should penetrate furthest, and the blue and green candy should be seen for the longest time. Many factors modify these results, including turbidity and color in the water. Results of trials will vary depending on the location and the characteristics of the water when the measurements were taken.

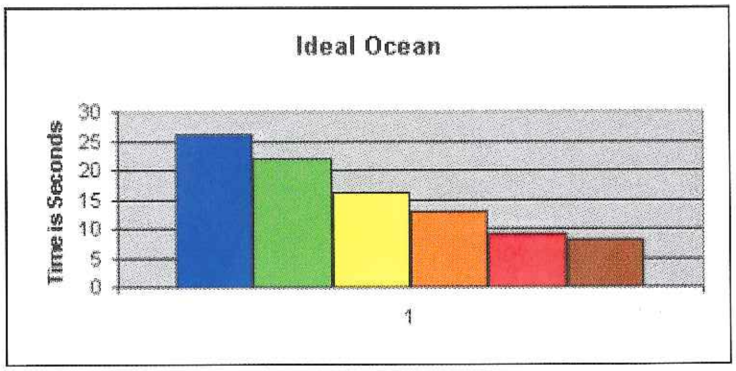
Candy Color	Time in Seconds @ Green Can Reef			
	Trial 1	Trial 2	Trial 3	Trial 4
Blue	5.45	6.8	6.5	6.6
Green	6.48	8.4	8.2	5.2
Yellow	5.41	9	8.7	7
Orange	6.04	8.2	8.9	6.4
Red	4.39	6.6	4.7	5.4
Brown	3.77	5.7	6.1	4.4



	Time in Seconds @ River Junction
Blue	1.4
Green	2.6
Yellow	3.3
Orange	3.1
Red	2.3
Brown	1.6



	Time in Seconds -- Ideal Ocean
Blue	26
Green	22
Yellow	16
Orange	13
Red	9
Brown	8



**The procedure used for this activity was developed by Dr. Russell Cuhel, Associate Scientist, Great Lakes WATER Institute, University of Wisconsin, Milwaukee)*

Wrap-Up

Have the students compare the results they got for each station or location. Were the results similar for each of the groups at a given station? If not, what variables could have caused the differences? Then have students compare the results from one station to another. Were there differences in the clarity or other appearances of the water from station to station? Could these differences have caused differences in the wavelengths of light that penetrate most or are absorbed most quickly?

Explain (or discuss) that in this experiment the time it takes for the candy pieces to drop through the water provided an indication of how deep into the water light of that color is traveling. A colored candy that can be seen for a longer time is falling deeper into the water than one that can be seen for a shorter time. So time is a substitute for water depth if you assume that all the candy pieces drop at a consistent rate. Measuring from the time the candy leaves the student's hand adds some time to each trial, but the amount of time spent by the candy in the air is essentially a constant value and so does not alter the overall results.

Another factor to explain (or discuss) is that, when the colored piece of candy disappears from sight, it does not mean that all light of that color is gone at that depth. The path the light travels is from the observer's eye through the air and water and then back again. Light is scattered and absorbed in both directions, so the actual penetration of a colored wavelength into the water will be greater than can be observed from the surface. Ask the students how they might design an experiment to reduce or eliminate this double pathlength problem?

Assessment: Have students:

- graphically present average values for each color at each station sampled by the group.
- compare the results of the trials - station-to-station; group-to-group - explaining possible reasons for differences among groups and/or stations.
- construct a short presentation, using computer programs and related technology, to describe the experiment and the results obtained. These presentations may be used during an open house or for a younger grade at the school.

Extensions

Have a local diver, or a teacher or student with diving experience, come to the class to talk about experiences with color in the water, perhaps showing pictures taken at various depths both with and without additional light. Perhaps a diver would be willing to take colored M&Ms, or colors painted onto a solid surface, down into the water at a station where students are also conducting this activity. The diver should record the depth at which each of the colors of candy 'disappears' from vision and turns to gray. Students can then graph the results and compare to their results.

Resources

Garrison, Tom. 1996. 'Ocean Physics,' Chapter Seven in *Oceanography: An Invitation to Marine Science (2nd Ed.),* Wadsworth Publishing, Belmont, California, 207 pages.

Thurman, Harold V. 1997. 'Properties of Water,' Chapter Six in *Introductory Oceanography (8th Ed.),* Prentice-Hall, Inc., Upper Saddle River, New Jersey, 544 pages.