What Color is the Ocean?

The color of an object is actually the color of the light reflected while all other colors are absorbed. Most of the light that is reflected by clear, open ocean water is blue, while the red portion of sunlight is quickly absorbed near the surface. Therefore, very deep water with no reflections off the sea floor appears dark navy blue. Near the Bahama Islands however, where the water is clear but also shallow, sunlight is reflected off white sand and coral reefs near the surface, making the water appear turquoise.

[Above] Deep, clear, open ocean water appears dark navy blue [*top right*], while shallow coastal waters surrounding islands can appear turquoise due to the reflection of white sand and coral reefs on the ocean surface [*middle and left*].

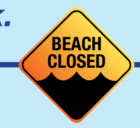
Credit: NASA

There are many places on Earth where water is not deep or clear, and therefore, not always blue. Suspended particles and dissolved material in water increase the scattering of light and absorb certain wavelengths differently, influencing the color of the water. For example, *phytoplankton* are microscopic marine plants that use chlorophyll and other light-harvesting pigments to carry out photosynthesis. *Chlorophyll* is a green pigment that absorbs the red and blue portions of the light spectrum and reflects green light. Ocean water with high concentrations of phytoplankton can appear as various shades of green, depending upon the type and density of the phytoplankton population. Other types of algae can make water appear reddish or deep yellow. Near coastal areas, dissolved organic matter, such as decaying plants, can produce a yellow or brown color. Soil runoff produces a variety of yellow, red, brown, and gray colors.

[Above] Sediment-laden water (brown and tan) pours into the northern Gulf of Mexico from the Atchafalaya River in this image taken on April 7, 2009.

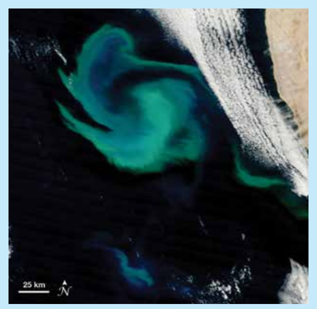
Credit: NASA

Smelly algae blooms as thick as guacamole closed Atlantic beaches, polluted lakes and rivers, and could even be seen from space in summer 2016. If you wanted to surf or go fishing in affected areas, you were out of luck.



[Above] Phytoplankton are the foundation of the aquatic food web, the primary producers, feeding everything from microscopic, animal-like zooplankton to multi-ton whales. Small fish and invertebrates also graze on the plant-like organisms, which are eaten by larger marine animals and so on. Like land plants, phytoplankton consume carbon dioxide and produce oxygen during photosynthesis. In fact, phytoplankton created about half the oxygen we breathe today. Phytoplankton are extremely diverse, varying from photosynthesizing bacteria (cyanobacteria), to plant-like diatoms, to armor-plated coccolithophores (drawings not to scale).

Credit: NASA



[Left] Phytoplankton growth depends on the availability of sunlight and nutrients. When conditions are favorable, phytoplankton populations can grow at a rate faster than they are consumed, a phenomenon known as a *bloom*. Phytoplankton blooms may cover hundreds of square kilometers and are easily visible from space. In this image, ocean waters glow peacock green off the northern Namibian coast on November 21, 2010. Phytoplankton blooms often occur along coastlines where deep, nutrient-rich waters well up from the ocean depths. The light color of this ocean water suggests the calcite plating of coccolithophores is turning the water milky.

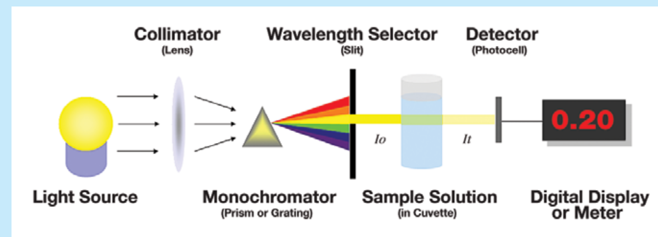
Credit: NASA

The image at right shows a harmful algal bloom in Florida on July 2, 2016. The bloom was caused by cyanobacteria, but not all cyanobacteria blooms are toxic.

Credit: NASA

Measuring Ocean Color: At Sea and From Space

Scientists can measure ocean color *directly*—by taking water samples from ships and permanent observation sites—or *indirectly*—using Earth-observing satellites that measure the amount of light backscattered and reflected from Earth's surface at various wavelengths. Unlike patchy ship-based measurements, satellites provide continuous global coverage over long timescales. NASA's Coastal Zone Color Scanner (CZCS) operated from 1978 through 1986, and was the first satellite ocean color mission and provided a proof-of-concept despite its limited view. The first dedicated global ocean color sensor, Sea-viewing Wide Field-of-view Sensor (SeaWiFS), operated from September 1997 until the end of the mission in December 2010. Today, NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the Aqua satellite (launched in May 2002) and the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite (launched in October 2011) routinely observe ocean color along with ocean color satellites operated by other countries.



[Above] *Spectrophotometry* is a method to measure how much light a water sample absorbs by measuring the intensity of light that passes through the solution. The diagram illustrates how a spectrophotometer works.

Credit: NASA

To continue the eighteen-year record of ocean color measurements, NASA plans to launch the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission in 2022. The Ocean Color Instrument (OCI) onboard PACE will provide the most advanced, continuous global observations at high-spectral resolution from the ultraviolet (UV) to near infrared (i.e., 350 – 800 nanometers), plus several short-wave infrared (SWIR) bands. PACE's broad spectral coverage will unveil a variety of new products to aid our understanding of the ocean as well as the atmosphere. Over the ocean, UV data will help discriminate between living and non living components of the upper ocean. Visible wavelengths will be used to identify the composition of phytoplankton communities.

Can we tell if a bloom is toxic from space? Not yet. Water quality managers use ocean color satellite data to decide where to take water samples to measure for toxins.

[Right] Ship-based optical instruments on ocean-going research vessels are often lowered into the water on a cable.

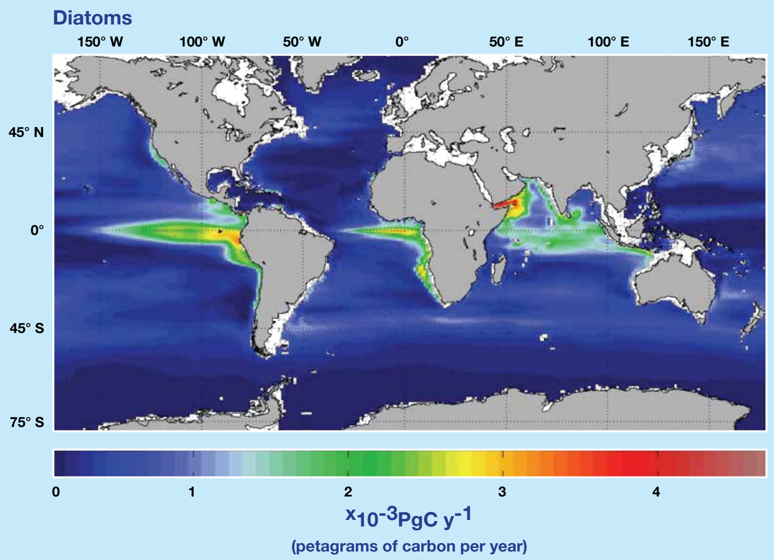
Photo credit: Joaquin Chaves, Ocean Ecology Lab Field Support Group, NASA's Goddard Space Flight Center

Cover image: This true color image of the North Atlantic Ocean was created using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership satellite collected on April 12, 2015. Notice the swirling phytoplankton eddies and different color coastal waters associated with runoff from the eastern United States. Credit: NASA

Modeling Phytoplankton

[Right] Coupled with ship-based measurements and computer models, satellite data allow scientists to observe and study different characteristics about the ocean and how they have changed over time, as well as predict how they might change in the future. This false-color image [*right*], generated using the NASA Ocean Biogeochemical Model, shows the primary production by diatoms, a group that tends to be large and contributes heavily to the global carbon cycle. Primary production reflects the amount of carbon that is converted using sunlight from carbon dioxide into organic carbon through a process called photosynthesis. The organic carbon represents the carbon that will be usable by higher trophic levels. These data help to improve our understanding of the global ocean carbon and biogeochemical cycles.

Credit: Cecile Rousseaux/USRA/NASA



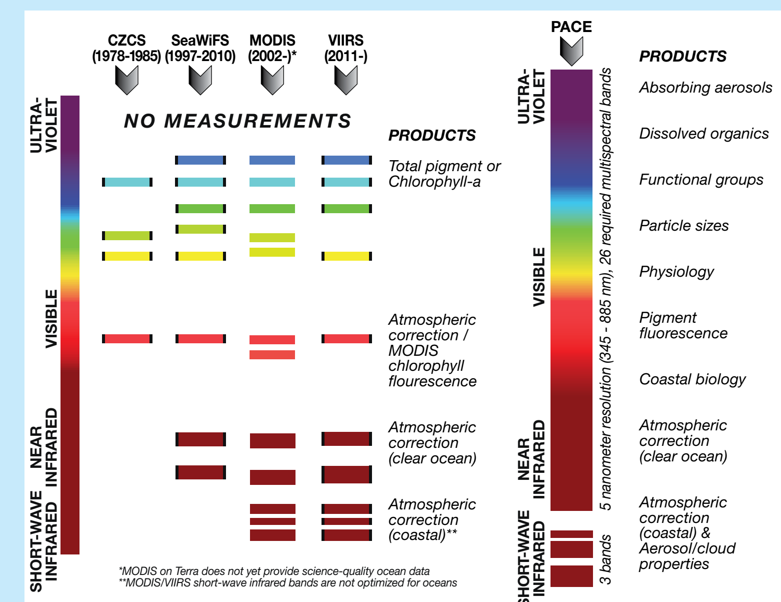
Spectral Coverage

Ocean Color Heritage Sensors compared with PACE

[Right] This graph compares the portions of the electromagnetic spectrum that the PACE Ocean Color Instrument will observe compared to previous NASA ocean color sensors. Human eyes are adapted to see a narrow band of this spectrum called visible light. Using satellite sensors to detect multiple spectral band combinations, scientists can study various aspects of ocean color in ways that they cannot from a photograph. Ocean color features, clouds, and aerosols each leave their signatures in the electromagnetic spectrum and scientists can observe and analyze these patterns to detect changes.

Find more information at *https://pace.gsfc.nasa.gov*.

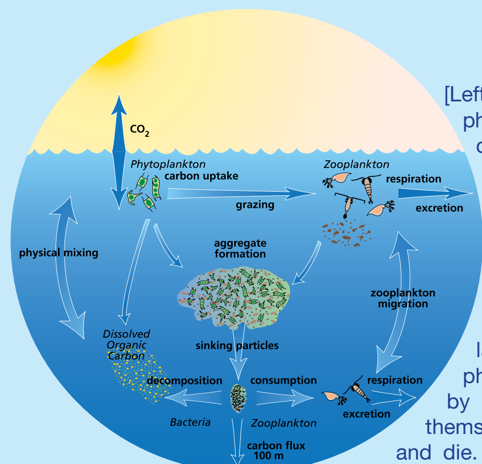
Credit: NASA



Why is Ocean Color Important?

Scientists use ocean color data to study:

- fundamental questions about phytoplankton blooms, the aquatic food web, and fisheries;
- the storage of carbon in the ocean and the role of the ocean in Earth's climate; and
- ocean health and water quality to assist resource managers.

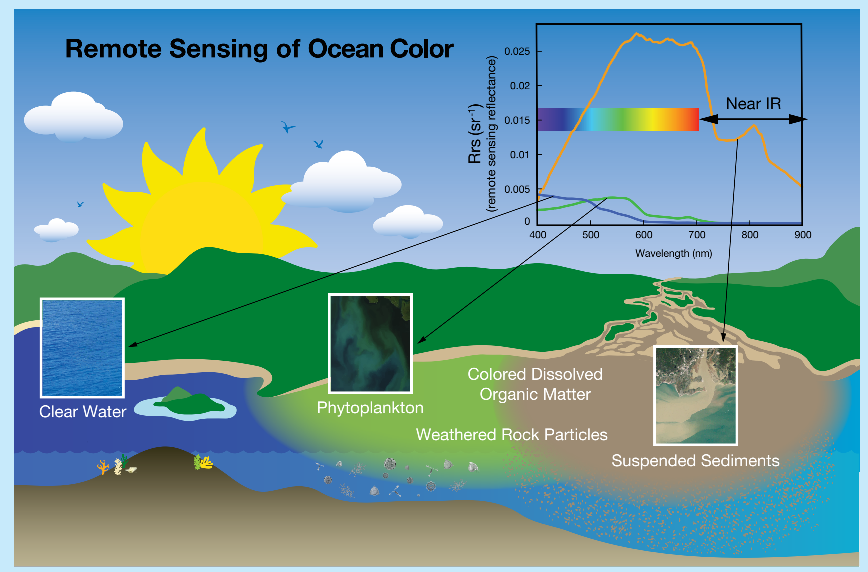


[Left] During photosynthesis, phytoplankton consume carbon dioxide on a scale comparable to land plants. Some of this carbon is carried to the deep ocean when phytoplankton die and sink, and some is transferred to different layers of the ocean as phytoplankton are eaten by other creatures, which themselves generate waste and die. Worldwide, this *carbon pump* transfers about 10 gigatonnes of carbon from the atmosphere to the deep ocean each year. Even small changes in the growth of phytoplankton may affect atmospheric carbon dioxide concentrations, which feed back to global surface temperatures.

Credit: U.S. JGOFS

[Left] Phytoplankton can be the harbingers of death or disease. Certain species of phytoplankton produce powerful toxins, making them responsible for harmful algal blooms, sometimes called *red tides*. Toxic blooms can kill marine life and people who eat contaminated seafood.

Credit: Kai Schumann, NOAA National Ocean Service



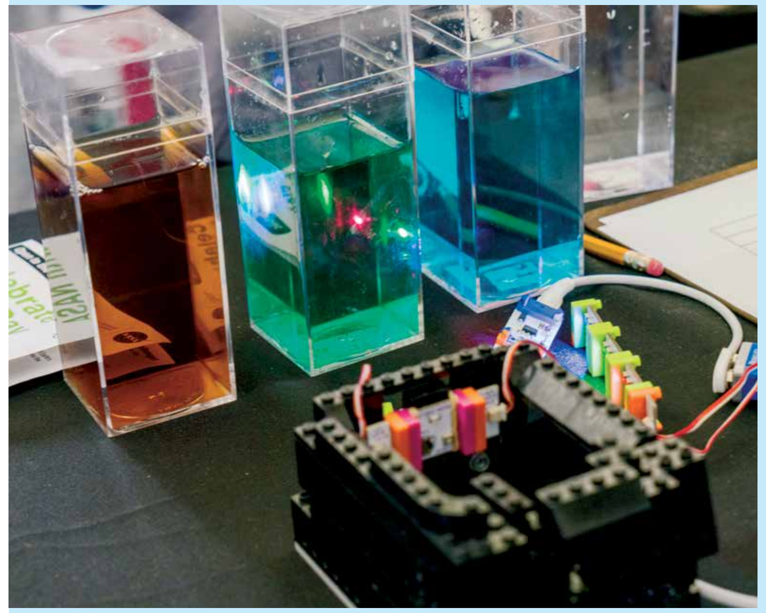
[Above] Scientists use a technique similar to spectrophotometry to quantify ocean color remotely. Satellite instruments (such as OCI) measure light reflected back to the satellite at different wavelengths and create emission spectra graphs [*inset, top right*]. Differences in the shape of the spectra can be used to determine what is in the water, such as sediments (orange line), chlorophyll (green line), or clear water (blue line). Brighter objects (e.g., sediments) reflect more light of all wavelengths while darker objects absorb more, thus the values are higher across the spectrum for sediment.

Credit: NASA

Simple Spectrophotometer Activity

In this activity, you will use an inexpensive, simple spectrophotometer* to test how light at different visible wavelengths (blue, green, red) is transmitted, or absorbed, through four different colored water samples. Clear water is used as the

Credit: NASA



Credit: NASA

"control," characterizing the light source and normalizing the other samples. The blue water represents the open ocean water with few plants—conditions you might find far from land in the middle of the ocean. The green water represents productive water with a high concentration of phytoplankton, i.e., a phytoplankton bloom. The tea water represents coastal water or river outflow that contains decaying organic material such as leaves.

**Note that a laboratory spectrophotometer is more sensitive than the one used in this activity.*

Setup and Investigation

1. Prepare four, square containers of water. One container should contain only clear water. For the other three containers: Put one drop of blue food dye in one, one drop of green food dye in another, and some tea (no leaves) in the last. Mix each container well.

2. Build a *light sensor* with battery + power + orange wire + sensor + number display—see *Materials Guide*.

3. Put together a *light source* with power + bright LED. Make sure you have three properly tuned* LED light sources (blue, green, red).

** Tune one LED light to red (tune up "r" with the littleBits™ screwdriver, tune down "g" and "b"), tune one LED to green (tune up "g," tune down "r" and "b"), and tune one LED to blue (tune up "b," tune down "r" and "g"). Make sure the LED light is not too bright. To do this, adjust the three light sources and/or the sensitivity of the detector so that the light sources put out distinct colors and read up to 98 when transmitted through clear water. Keep the same settings for the entire experiment.*

4. Attach the *light sensor* to one side of the black base and place the blue LED *light source* on the opposite side of the black base. The *light source* should be level with (and shining directly on) the *light sensor* on the opposite side of the black base.

5. Put the clear water sample into the black base and turn on the blue LED light so that the blue light shines through the container of clear water and is received by the *light sensor* on the opposite side. Cover the spectrophotometer (black base, light sensor, and light source) and water sample with a black cloth to minimize background light.

6. Record the value on the light sensor (received by the blue LED light) for clear water in **Table 1**. Remove the blue LED light. Insert the green LED light and record the value on the *light sensor* for clear water in **Table 1**. Remove the green LED light. Insert the red LED light and record the value on the *light sensor* for clear water in **Table 1**. Repeat for all colored water samples (blue, green, tea), completing **Table 1**.

Table 1

Sample	Sensor Value for Blue LED light	Sensor Value for Green LED light	Sensor Value for Red LED light
Clear water			
Blue water			
Green water			
Tea water			

7. Circle the highest sensor value for each colored water sample in **Table 1**. Do you notice a pattern?

8. Calculate the percent of light transmitted for each colored water sample in **Table 2**. To do this, divide each colored water sensor value from **Table 1** by the clear water sensor value for the corresponding light color and multiply that value by 100 to get the percentage of light transmitted. For example, (blue water sensor value for blue LED light) ÷ (clear water sensor value for blue LED light) x 100 = (percentage of blue light transmitted). Calculate and record each percentage in **Table 2**.

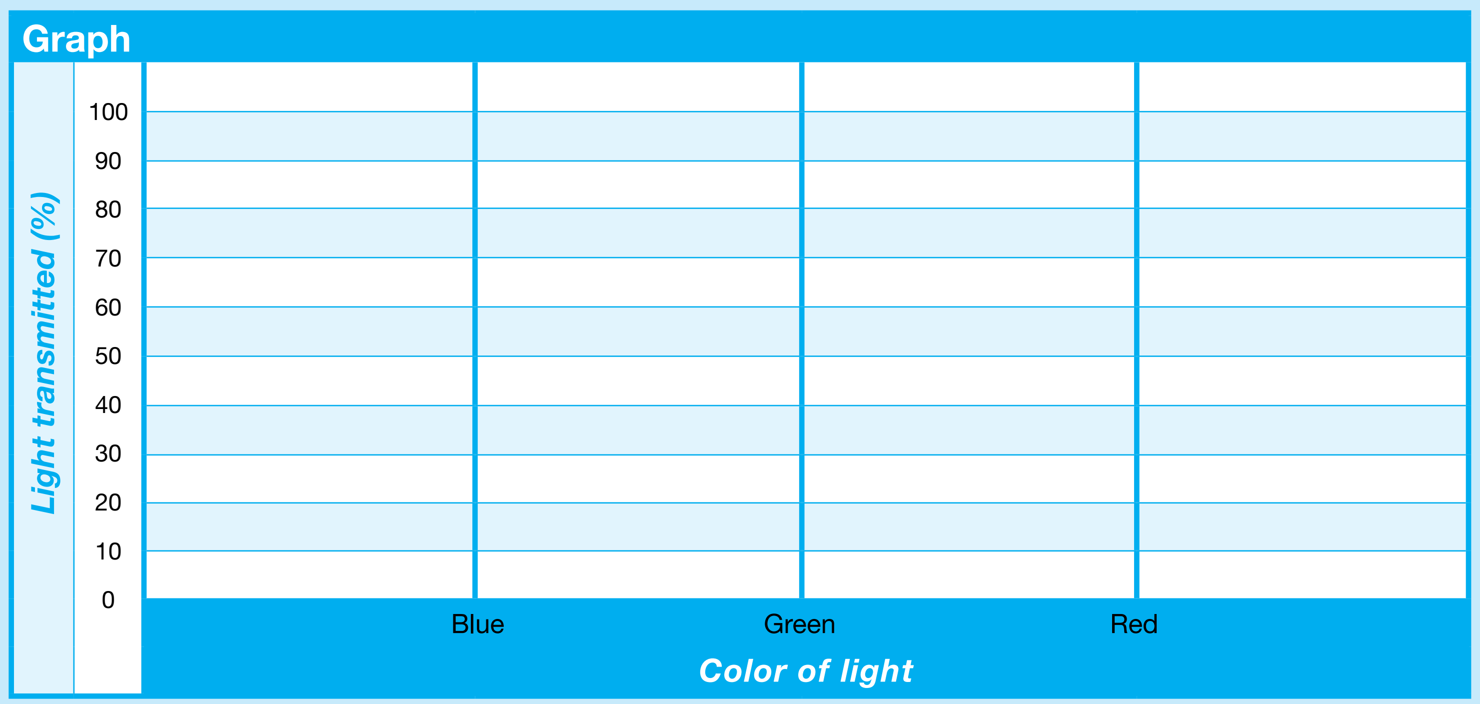
Table 2

Sample	% of Blue light transmitted	% of Green light transmitted	% of Red light transmitted
Clear water	(clear water sensor value for blue LED light) ÷ (clear water sensor value for blue LED light) x 100 = **100**	(clear water sensor value for green LED light) ÷ (clear water sensor value for green LED light) x 100 = **100**	(clear water sensor value for red LED light) ÷ (clear water sensor value for red LED light) x 100 = **100**
Blue water			
Green water			
Tea water			

9. Plot the values from **Table 2** on the **Graph** for all three colored water samples (blue, green, red) using three corresponding colored pencils (blue, green, red).

10. Discuss the results revealed in **Table 2** and the **Graph**.

Graph

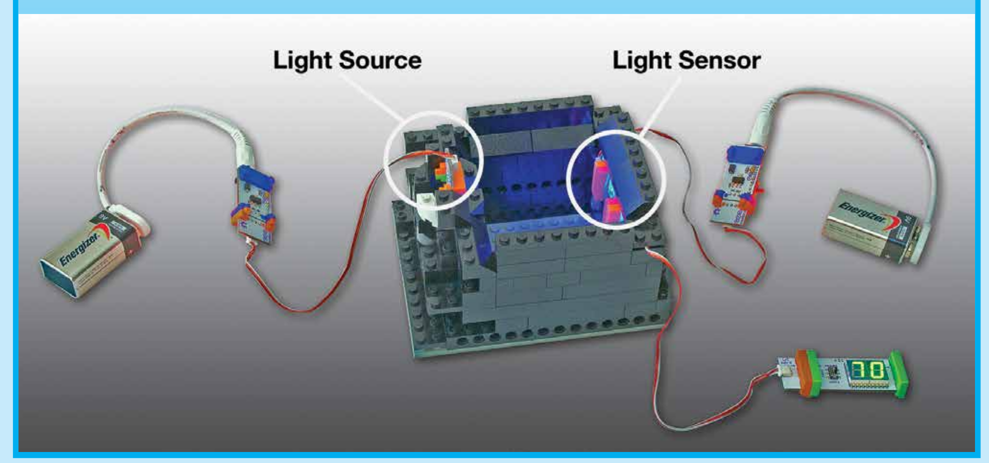


Results

The color of the water affects how much light from the light source is transmitted or absorbed before reaching the light sensor. Specifically, the *spectrum* (i.e., graph) for each colored water sample demonstrates that the highest percentage of light transmitted through a medium corresponds most closely to the color of its constituents while the other colors are absorbed. In other words, the blue water transmits the highest amount of blue light and absorbs green and red light. Likewise, the green water spectrum peaks at green and the tea water spectrum peaks at red. These are called *spectral signatures*. While ocean color satellite sensors measure reflected light—not light that is transmitted across a water sample like a spectrophotometer does—scientists are able to remotely sense the same spectral signatures, allowing them to observe and analyze changes in ocean color.

Materials Guide

- littleBits™ components or their equivalents:
  - 2x battery + cable https://shop.littlebits.cc/products/battery-plus-cable
  - 2x power bit https://shop.littlebits.cc/products/littlebits-power
  - 3x rgb LED https://shop.littlebits.cc/products/rgb-led
  - 3x wire https://shop.littlebits.cc/products/wire-bit
  - 1x light sensor https://shop.littlebits.cc/products/light-sensor
  - 1x number output https://shop.littlebits.cc/products/number-bit
- Two 9V batteries
- Four square, clear containers of clean tap water
- Blue and green food dye
- Cooled tea
- Three colored pencils: blue, green, red
- Calculator
- Black cloth to cover water sample and minimize ambient light
- A black base into which the square water containers fit. You should be able to secure the LED light(s) on one side of the base and the light sensor directly across—see photo below
  Note: A simple Lego® structure is used.



Reference:

Schollaert Uz, S. 2016. Building intuition for in-water optics and ocean color remote sensing: Spectrophotometer activity with littleBits™. Oceanography 29(1):98–103, https://dx.doi.org/10.5670/oceanog.2016.01