Playing with light/optics relevant for sensing

GOALS FOR PLAYING WITH OPTICS LAB

Introduce the students to nomenclature and concepts associated with marine optics.
Concept introduced:

> What determines the colors we observe?
> Absorption, attenuation, scattering and fluorescence.
> Reflection, diffraction and refraction – the three components of scattering.
> Law of Beer, Lambert and Bouguer for attenuation.
> How does a spectrophotometer work?
> How do we decompose white light into its components?
> What is polarization?

LABORATORY SAFETY ISSUES– ***No hazardous chemicals; general laboratory safety; do not look directly at the sun<http://eclipse.gsfc.nasa.gov/SEhelp/safety2.html>; avoid contact with eyes in the labs with laser pointers***< the classic laser lab warning sign is "*Do not look at LASER with remaining good eye*"!>

LAB DIRECTIONS:

This is a free-flowing lab designed to remind you things you already know and tease you to explore things you don't know. Choose one or two class mates and migrate through the activities. Make sure to discuss the process and results with each other. If you are not sure about your understanding of a concept, talk to an instructor.

Station 1. Decomposing white light into its spectral components:

Relevance: many sources and detectors in optical instrument use these methods to obtain/radiate light for a specific portion of the visible spectrum.

a. Use a prism to decompose visible (white) light into its components (use either sunlight or a flashlight). For which wavelengths (blue or red) is the index of refraction of the prism higher (the ray's propagation angle is bent the most by the prism)?
b. Use a diffraction grating to decompose visible (white) light into its components using a tube with the grating mounted at one end and a slit at the other; look into the tube on the grating side. Which wavelength (short-blue or long-red) has constructive interference closest to the center?
c. Shine a red laser through a diffraction grating transmission slide onto a piece of white paper and observe the spots that form due to constructive interferences. How would the results differ for a blue wavelength? Try it. How do they differ for a diffraction grating with more/less lines per mm? Try it.
d. Can you think of applications for which you would want to separate light into its spectral components?

Station 1b. Using a handheld spectroscope to qualitatively analyze the color transmitted through a substance:

a. Look through a spectroscope at white light in the lab and natural light outside (the source has to be seen through the slit, do NOT look directly at the sun!!!). Describe any observed difference in color.
b. Predict what you will see if you looked through a container of water with food coloring.
c. Test your prediction by putting a test tube of water with food coloring in front of the small slit of the spectroscope. Describe the change in the color spectrum seen. Note: the spectroscope used here is analogous to the tube used in Station 1.

Station 2A. Color attenuation, using red, blue, and green LED lights and containers of red, blue and green dyed water.

Relevance: properties of the medium such as absorption and scattering determine the intensity and color of light transmitted through and reflected by the medium.

a. Predict which wavelengths are likely to be most absorbed in each container and which are most likely to propagate through with least attenuation.
b. Test your prediction with LED flashlights. Which colors propagate through which container. Qualitatively compare intensities of transmitted light for each combination of LED light and water color.

Station 2B. Measuring color attenuation, using littleBits setup with variable (red, blue, and green) LED lights and containers of clear, red, blue and green dyed water (same ones you used for **2A**).

a. Test your prediction with littleBits setup. Measure the light transmitted in all (4) containers, with three LED lights. Write in your observations in the table, and calculate % transmitted as value measured in colored water/value measured in clear water. How do these values compare with your hypothesis, and "eye" based measurements?

	Blue LED		Green LED		Red LED	
Sample	Value	% transmitted	Value	% transmitted	Value	% transmitted
Clear water						
Blue water						
Green water						
Red water						

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Station 2C: Color of an object
Relevance: understanding what determines a color we observe is key to understanding 'ocean color'.

Shine a red light on a 'white' wall. What color do you observe? Shine a white light on a red page. What color do you observe? What color will the red page have if illuminated by blue light? Repeat the above viewing the object through colored transparent papers positioned in front of your eye (the receiver).

How do the absorption by the paper, the reflection by the paper, the properties of the light source and off the receiver (your eye + filter in front of it) affect the color observed? How is this activity relevant to the color of the ocean as observed from a satellite?

Station 3A. Scattering of light by particles.

a. Shine the laser through the end of an empty tank. Can you see the laser in air (do NOT look directly at the laser)?
b. Do the same in a tank filled with tap water. Is transmission different than in air?
c. Shine the laser in a tank filled with water where a few drops of Maalox were added (Maalox contain small particles). How did the appearance of the laser change? Why?
d. Can you relate your observation to lasers shooting in space in science fiction movies?

Station 3B Scattering of light by particles

a. Shine the laser at carbohydrate beads in air.
b. Shine at the laser at the same beads in water after they swelled up (grew by absorbing water).
c. Which scatter more light? Why do you think they did/did not?

Station 3C. Index of refraction matching.

a. Put a dry glass rod in water. Can you see it?
b. Now, wipe the rod and put it in a glass with mineral oil. What happened to the rod?

By matching the index of refraction of the rod and fluid, light is not scattered and we cannot see it.

Shine a light through a glass with swelled carbohydrate beads or crystals. Can you see them? The material they are made of is quite refractive but because so much water is added to them when they swell their effective index of refraction matches that of water (phytoplankton have a low index of refraction relative to water due to their high water content compared to that of their constituent materials).

Relevance: scattering occurs when light from one medium interact with matter with made of a material where it propagate with a different speed (that means it has a different index of refraction). For similar shape and size, the more different is the index of refraction the larger is the scattered light. The effective index of refraction of phytoplankton and bacteria is low, not because the constituent materials (cell wall, carbohydrates, proteins) have a low index of refraction but because they contain a large amount of water).

Station 4. Remotely observed color.

Fill the containers to about 700ml with tap water.

a. Analogue to deep ocean color: Add about 20 drops of green food coloring into the container with a black bottom. What color is the water?
b. Add Maalox into the colored water. What color is the water?
c. Now repeat this experiment (same amount of water and drops of color and Maalox) in a tank with a reflective bottom. How is it different from the previous one?

Relevance: intensity of light emitted from water is proportional to scattering and inversely proportional to absorption (for a given intensity of impinging light).

Station 5A. Fluorescence emission of a column with different fluids (in hood of dark room). Fluorescence is the name of the phenomenon whereby light absorbed at one wavelength is emitted at another, less energetic wavelength (Stokes' shift).

a. For each column with fluid, shine white light at the column. What is the color of each fluid?
b. Shine UV light at the column by sliding the switch of the light below the columns to the left. Does is the color of each fluid change?

Station 5B. Fluorescence emission of spinach extract (in hood of dark room).

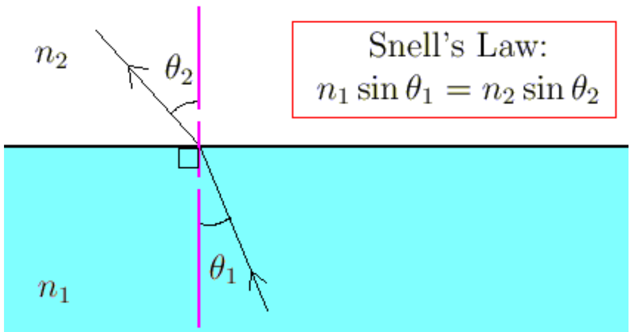
Observe the color transmitted through a spinach extract in 90% acetone. What does the color tells you about its absorption properties.

a. Shine a violet laser at the extract and observe the light emitted. What color do you observe?
b. Hold the red filter between the light and the spinach extract. Observe the light emitted at a 90º angle and place a blue filter between the tube and your eye. What color do you observe?
c. Now reverse the position of the filters (blue filter between light and spinach extract; red filter between extract and your eye). What color do you observe?
d. Can you use this observation to design an instrument to measure the concentration of the fluorescing pigment?

Relevance: fluorescence by chlorophyll *a*, other pigments, and colored dissolved organic material (CDOM) can be used to detect chlorophyll *a* and CDOM in-situ.

Station 6A. Refraction of waves passing through mediums with different transmission properties.

Relevance: when light crosses from the sun into the ocean or an instrument into the water (or back into a receiver) the light beam gets refracted and reflected. This affect how light penetrates (leaves a medium) and in the case of instrument it affects, for example, its acceptance angle.



Shine a laser pointer into the center of the side of the water tank (do NOT look directly into the laser). Observe the angle change due to refraction.

a. At which angle does the light beam change direction the most?

b. Which angle gives the least effect?

c. What is the maximum angle for the light beam in the water?

d.Total internal reflection

Through the sides of the tank, shine the laser towards the air from the water side. You will observe that at some angles the light completely internally reflects. This angle, called the critical angle, defines a circle for an observer looking at the water surface from below beyond which (that is at higher angles of observation) all the light comes from below the surface. Rotate the laser by 90 degree. How is the intensity of the beam coming back changing? (to explain this observation, you will need to know something about polarization).

This angle is called the critical angle. A diver looking at the ocean surface from below will see a circle separating light coming mostly from above the surface and light at higher angles of observation reflecting down from below the surface (Fig. 1).

Fig. 1 Snell's circle as viewed by a diver (http://www.bsoup.org/Beginners_Portfolio/2005/BP2005.php).

Station 6B. Refractometer.

A refractometer is a device used to infer properties of matter by looking at the angle light refract as it passes through the material. The one you will use is designed to provide salinity.

a. Put a drop of fresh water on the refractometer and read the salinity by looking through the refractometer.
b. Repeat with a drop of salt water from the dock. What is the approximate salinity at the dock?

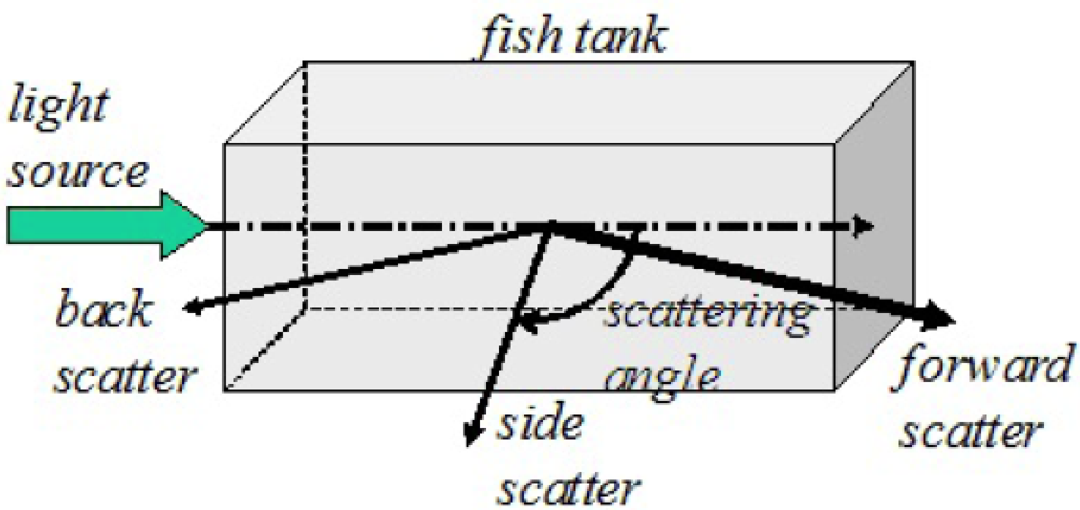
Note: the ratio of the indices of refraction of two media for a given wavelength is inversely proportional to the ratio of the speeds of light in both media. In which media does light propagate faster: Water or air?

Station 7: Polarization

Relevance: scattering and reflection affect the polarization state of light interacting with matter. Polarization is a relatively new frontier in ocean optics and has been shown to be useful to avoid glare, and help characterize the composition of particulate materials in the ocean.

a. Scattering of a light beam

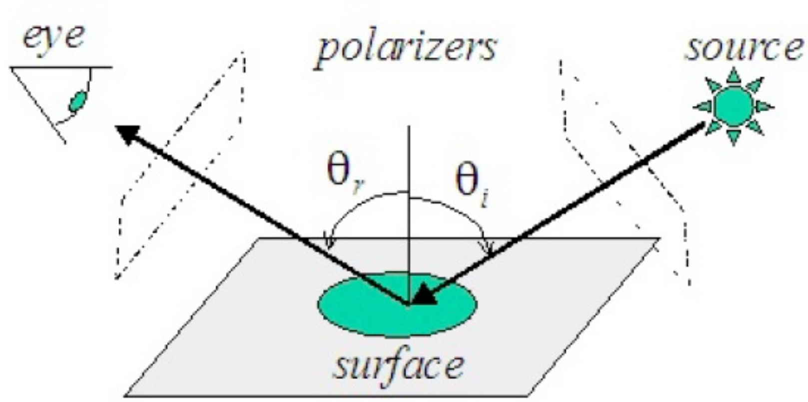
a. Shine a collimated light source through from the sides of an aquarium. Add a few drops of Maalox and observe the intensity of the beam as function scattering angle (relative to the direction of propagation, see diagram) and azimuth angle. How does the intensity change?



b. Holding a linear polarizer, observe the beam at 90degree scattering angle and rotate the polarizer on its axis. Does the intensity change with the axis of your polarizer? Now observe the beam from other scattering angles. How does the relative change in intensity (between the two axes of polarization) vary with scattering angle?

c. Do the same experiment but with a laser as a source. Observe the beam through the polarizer from a 90 degree scattering angle as you rotate the laser on its axis (shining in the same direction). Can you explain the observation given the fact the laser is linearly polarized?

b. Reflection from surfaces



Look at the specular reflection of a collimated unpolrized light from a smooth non-metalic surface (e.g. plastic, wood, or water). View the surface through a linear polarizer.

a. How does the intensity vary with the direction of the polarizer?

b. What if you use a polarizer in front of the source before it interacts with the surface?

c. How different are the result for a metallic surface?

Station 8. Lenses — converging and diverging lenses:

Relevance: imaging systems and instrument where source/receiver optics needs to be collimated (propagating nearly in straight lines) or redirected (e.g. to a detector). Lenses provide a means to do it with little loss of energy.

a. Shine two laser beams through a lens onto a white paper (or wall). Can you make their beam converge at a single location?

b. Change the relative position of source and lens and see how the image size is affected.