Lab 1: Playing with Light and Optics Relevant for Remote Sensing
8 July 2013

GOALS FOR LAB ON 'PLAYING WITH LIGHT':

Introduce students to nomenclature and concepts associated with marine optics.

Concepts 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?

One calculation in Beer's Law exercise:

Calculate the specific attenuation for food coloring and Maalox in the Beer's Law exercise.

LABORATORY SAFETY ISSUES:

No hazardous chemicals.
Practice 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"!

GENERAL DIRECTIONS FOR THIS LAB

This is a free-flowing lab designed to remind you of things you already know (but might have forgotten) and to tease you to explore things you don't know. Choose one or two classmates and migrate through the activities. Discuss the process and results with each other. If you are not sure you truly understand the concept, talk with an instructor.

Station 1. Decomposition of white light into its spectral components:

Relevance: many sources and detectors in optical instruments use this approach to emit or collect light for a specific region of the visible spectrum.

a. Use a prism to decompose visible (white) light into its components. The source may either be sunlight or a flashlight. For which wavelengths (blue {shorter wavelength} or red {longer wavelength}) is the index of refraction of the prism higher (i.e., which ray 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 (blue or red) has constructive interference closest to the center?

c. Shine a red laser through a diffraction grating transmission slide and observe the spots that form due to constructive interferences. How would the results differ for a blue wavelength?

d. Can you think of applications for which you would want to separate light into its spectral components?

Station 2. Transmission of light through a substance (air and water):

a. Look through a handheld spectroscope, with a build in prism, at a white light source first in the lab and then outside — caution, the source has to be seen through the slit; do NOT look directly at the sun!!! Describe the observed differences 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 3. Spectral attenuation:

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

Station 3A. Spectral attenuation of light using red, blue, and green LED lights and solutions of red, blue and green dyed water.

a. Predict which wavelengths are likely to be most absorbed in each container and which are most likely to propagate through the medium with the least attenuation.

b. Test your prediction with LED flashlights. Which colors propagate through which containers. Qualitatively compare intensities of transmitted light for each combination of LED light and water color.

Station 3B. 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 for a tank filled with tap water. Is the transmission different than in air?

c. Shine the laser in a tank filled with water and an addition of a few drops of Maalox (Maalox is a suspension of small particles of aluminum hydroxide and magnesium hydroxide). Did Maalox change the appearance of the laser change? In what way? Why?

d. Can you relate your observation to scenes in science fiction movies where lasers are shooting into space?

Station 3C. Remotely observed color:

Fill the containers with about 0.7 L tap water.

a. Analogue to deep ocean color: Add about 20 drops of green food coloring into the container with a black bottom. Shine white light into the water from above. What color is the water?

b. Add Maalox into the colored water and shine the light into the 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 does the color of the water differ from the previous cases?

Station 4. Fluorescence – the phenomenon whereby light absorbed at one wavelength is emitted at another, less energetic wavelength; Stokes' shift is the remission of an absorbed photon at a lower frequency, longer wavelength.

Relevance: fluorescence by chlorophyll *a* and colored dissolved organic material (CDOM) affects ocean color; fluorescence can be used to detect chlorophyll *a* and CDOM in-situ.

Station 4A. Fluorescence emission of different fluids in a dark room:

a. For each column of water with a fluid, shine white light at the column. What is the color of each fluid?

b. Shine UV light at the column. Does the color of each fluid change?

Station 4B. Fluorescence emission of a spinach extract in a 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 blue light at the extract and observe the light emitted at 90º angle to the side of the incoming beam. 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?

Station 5. Lenses — converging and diverging:

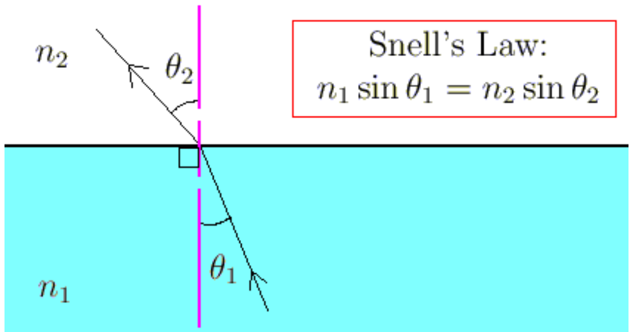
Relevance: imaging systems and instruments where the source and/or the receiver optics need to be collimated (propagating nearly in straight lines) or redirected (e.g. to a detector). Lenses provide a means to do converge or diverge light with little loss of energy.

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.

Station 6. Refraction

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. Refraction affects how light penetrates (or leaves a medium); in the case of instrument, refraction affects its acceptance angle.



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

a. 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.
   - At which angle does the light beam change direction the most?
   - Which angle gives the least effect?
   - What is the maximum angle for the light beam in the water?

b. 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: Additive vs. subtractive color:

Relevance: understanding what determines a color is key to understanding 'ocean color'.

a. 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 would the red page be if you illuminated it with blue light?

b. Repeat the above sequence, this time viewing the wall or paper through colored transparent papers positioned in front of your eye (the receiver).

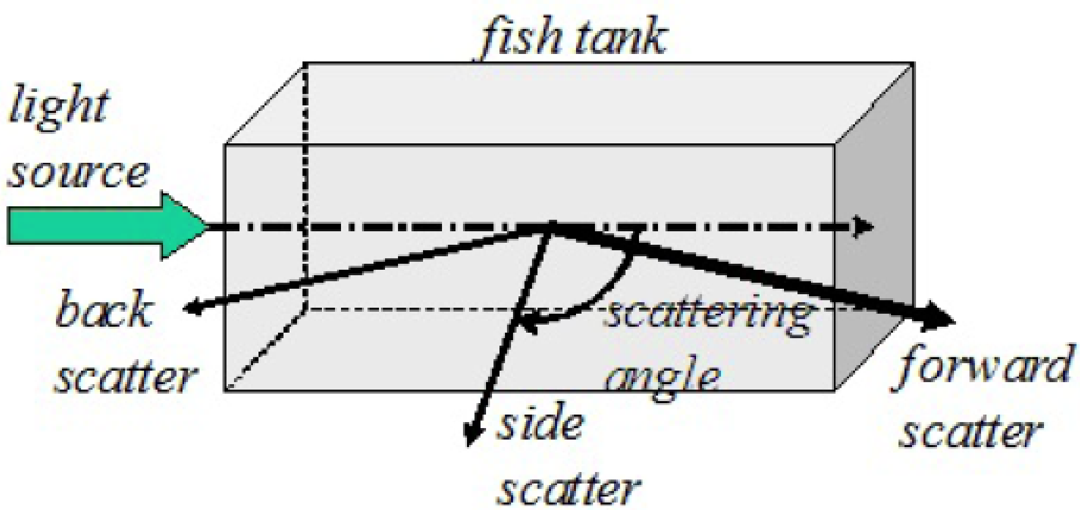
c. How does absorption by the paper, reflection by the paper, properties of the light source and the receiver (your eye + filter in front of it) affect the color observed? How is this activity relevant to the color of the ocean as observed from a satellite?

Station 8: 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.

Station 8A: Scattering of a light beam.

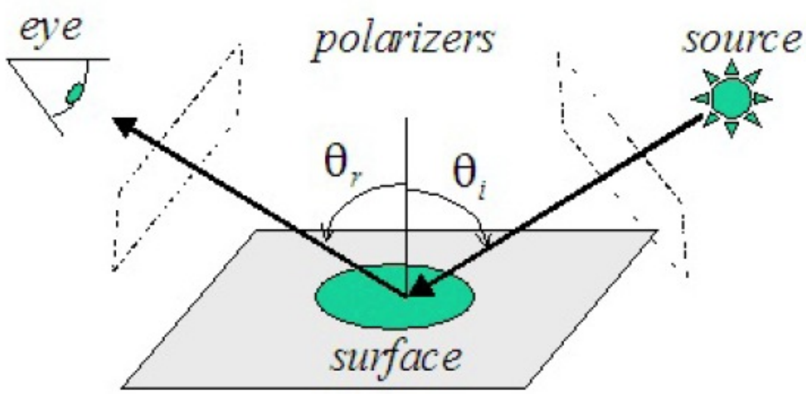
a. Shine a collimated light source through from the sides of a fish tank aquarium. Add a few drops of Maalox and observe the intensity of the beam as a function of scattering angle (relative to the direction of propagation, see diagram) and azimuth angle. How does the intensity change?



b. Hold a linear polarizer and observe the beam at a 90º scattering angle. 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?

Station 8B. Reflection from surfaces



Look at the specular reflection of a collimated unpolarized light from a smooth non-metallic 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 9. What does it mean to say something is a certain color?

Relevance: the human eye is a great instrument (in terms of its dynamic range of intensity perception) however it only has three types of cone cells to detect electromagnetic radiation with (an analogy may be to writing a poem with only three letters). To increase the information content from space sensors we need to increase the number of spectral bands.

Curt's laptop displays 6 windows with different colored backgrounds. The spectra plotted in each window show normalized spectra measured on common objects, like a red laser or green book cover.

a. Look at the white window with the magnifier so you can see the individual pixels. You can see that red, green, and blue pixels are illuminated. As you saw in the prism exercise, white is composed of all colors, so red + green + blue mixed together gives white.

b. Now look at the red screen. You see that only the red pixels are illuminated and the green and blue ones are turned off and look black. Check the green and blue screens.

c. Now look at the yellow screen. What pixels are illuminated? Are there any yellow pixels in the computer screen? What does it mean to say something is "yellow" if there is no yellow light present?

d. Check the purple screen. What pixels are illuminated? Could you make a laser that emits a single wavelength of purple light, like the red laser spectrum plotted on the red screen?

Station 10. Schlieren - effect of density stratification in the medium on the measurement of transmission.

Relevance: Density variability in the medium along a light beam causes refraction in the beam, and potentially a noisy signal over time.

Materials: laser pen and a 10 cm C-Star transmissometer in a tank with stratified water.

a. Carefully position the sensor near the surface (without mixing the tank); record the approximate depth and record the average voltage reading.

b. Place the sensor near the center of the tank. Create turbulence by stirring the water using a ruler. Observe the signal. Shine a laser pen parallel to the bottom and watch the dot of its beam. Watch it change over time, as the turbulence subsides.

Station 11. Beer-Lambert-Bouguer Law (see appendix for a description of this law).

Relevance: the consequences of this law is that optical properties (absorption, scattering and attenuation) of dilute materials are additive. This concept is crucial to our understanding of how the optical properties of different materials interact in fluids.

Materials: two clear tank with water, a collimated white light source (put a filter in front if you want a colored source), a light detector, tape, ruler (meter stick), dropper, food coloring (absorbing, dissolved material), Maalox (highly-scattering, non-absorbing material).

Station 11A. Beer-Lambert-Bouguer Law with a scattering material (Maalox).

Follow directions below. Record your results in the worksheet.

a. In a clean tank, write the amount of light arriving at the detector when only water is present (this is your reference reading, I_0)..
b. Add **one drop** of Maalox, mix thoroughly, and write the value of the signal arriving at the detector, I_1.
c. Add **one drop** of Maalox, mix, and the value of the signal arriving at the detector, I_2.
d. Add **two drops** of Maalox, mix, and the value of the signal arriving at the detector, I_4.
e. Continue **doubling the number of drops** added (four drops, eight drops, etc.) until the signal arriving to the detector is less than 50% of the pure-water signal.

B. Beer-Lambert-Bouguer Law with an absorbing material (food coloring dye):
Follow directions in the table below. Record your results in the work sheet.

a. In a clean tank, write the amount of light arriving at the detector when only water is present (this is your reference reading, I_0).
b. Add **one drop** of dye, mix thoroughly, and write the value of the signal arriving at the detector, I_1.
c. Add **one drop** of dye, mix, and the value of the signal arriving at the detector, I_2.
d. Add **two drops** of dye, mix, and the value of the signal arriving at the detector, I_4.
e. Continue **doubling the number of drops** added (four drops, eight drops, etc.) until the signal arriving to the detector is less than 50% of the pure-water signal.

Maalox:			
n = # drops	**Detector signal, I(n)**	**Transmittance = I(n) / I(0)**	**% Transmittance = I(n) / I(0) * 100%**
n=0			
n=1			
n=2			
n=4			
n=8			
n=16			
n=32			
Food color (dye) **Color used:**			
n = # drops	**Detector signal, I(n)**	**Transmittance = I(n) / I(0)**	**% Transmittance = I(n) / I(0) * 100%**
n=0			
n=1			
n=2			
n=4			
n=8			
n=16			
n=32			

To do (on your computer):

1. Plot the transmittance I(n)/I(0) as function of numbers of drops, either food coloring or Maalox. What function best describes the shape of the curve?
2. Plot ln[I(n)/I(0)] as function of numbers of drops. What function best describes the shape of the curve?
3. Using equation 1A in the appendix, ($I_n/I_0 = e^{-\varepsilon(\lambda) * c * L}$), calculate the specific attenuation (ε) of Maalox and food coloring (for the specific color you chose). You

will need the length of the tank (*L;* in m) and a measure of concentration (*c*; use number of drops).

4. What physical unit does ε have?
5. What wavelength should we assign to ε ?

You can further explore Beer's law by logging into:
http://www.chm.davidson.edu/ChemistryApplets/spectrophotometry/EffectOfCellPathLength.html
http://www.chm.davidson.edu/ChemistryApplets/spectrophotometry/EffectOfConcentration.html

APPENDIX

Law of Beer, Lambert and Bouguer

Light is electromagnetic radiation that is visible to the human eye (about 400-700nm). As light propagate within a medium it interacts with the medium: some of the radiation continues without change, that is the transmitted radiation, some of the radiation is lost, we refer to this process as absorption, and some is redirected, we refer to this process as scattering. Starting in the 18^{th} century, scientists observed that:

1. There is a relationship between the degree that light attenuates within a medium and the concentration of the material within that medium.
2. When formulated in terms of the attenuation coefficients (see below), the contributions by different substance in a mixture to the total attenuation are additive, that is if we have two substance attenuating within a medium their combined attenuation equals the sum of the attenuation by each substance individually.

Note: only when scattering is negligible (e.g. as often occurs with truly dissolved substances) does attenuation equals absorption. In the 20^{th} century derivations of this law were formulated based on target probability theory in a random medium (e.g. Kostinski, 2001).

Assume a source of light of a given wavelength, λ, of intensity I_0 at the point where it enters the medium and intensity *I(L)* at a distance *L* away from the source. The law of Beer, Lambert and Bouguer states that:

$$\frac{In(\lambda)}{I_0(\lambda)} = e^{-\varepsilon(\lambda)[C]L} \qquad (1A)$$

Where *[c]* denotes the concentration of the material, $\varepsilon(\lambda)$ is the concentration-specific attenuation (a property of the material and the measurement geometry) or absorption (if scattering is negligible). Whichever we measure is based on the measurement setup and properties of the substance as you will later learn. This equation allows one to compute the concentration of a given material given we that we know its ε. Convince yourself you can derive [c] from the above equation if you know the instrument length *L*, ε and I_n/I_0. Note that εmay also vary as function of physical parameters such as temperature and salinity.

History (from http://www.worldhistory.com/wiki/B/Beer-Lambert-law.htm):
Beer's Law was independently discovered (in various forms) by Pierre Bouguer

(Mathematician and hydrographer, France) in 1729 Johann Heinrich Lambert (Physicist and astronomer, Germany, who contributed much to optics, in particular the law about reflection from surfaces) in 1760, and August Beer (Mathematician, chemist and physicist, Germany) in 1852.

A spectrophotometer is a device for measuring light intensity that can measure intensity as a function of the wavelength of light (e.g. http://en.wikipedia.org/wiki/Spectrophotometer). Spectroscopy (http://www.scienceofspectroscopy.info/) is the branch of science using spectrophotometer to study matter. In this lab we will build a rudimentary setup to measure the specific attenuations of food coloring and Maalox one an absorbing and the other a scattering substance.

REFERENCES

Boss, E., 2005. Teachable optics. Absorption, Scattering, and the Color of the Ocean. OPN, Nov. 2005, 12-13. (http://misclab.umeoce.maine.edu/documents/BossOPN.pdf).

Kostinski, A. B., 2001. On the extinction of radiation by a homogeneous but spatially correlated random medium. J. Opt. Soc. Am. A. 1929-1933.

Shifrin, K. 1988. Physical Optics of Ocean Water. AIP. 285pp.