Lab 1: playing with optics (Part II, E. Boss) 2 July 2007

SMS 598: Application of Remote and In-situ Ocean Optical Measurements to Ocean Biogeochemistry.

LOCATION: MITCHELL LAB.

GOALS FOR PLAYING WITH OPTICS LAB

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

Concept introduced:

Absorption, attenuation, scattering and fluorescence.
The Law of Beer, Lambert and Bouguer for attenuation.
What is a spectrophotometer?
What is spectroscopy?
What is a spectroscope?
What is polarization?
Reflection, diffraction and refraction, the three components of scattering.

Calculation:

Calculate the specific attenuations for a drop of food coloring and a drop of Maalox in the Beer's Law exercise.

LABORATORY SAFETY ISSUES – None no hazardous chemicals; general laboratory safety; do not look directly at the sun; avoid any contact with an eye in the labs with laser pointers

LAB DIRECTIONS:

Station 1. Decomposing white light into its components:

a. Use a prism to decompose visible (white) light into its components (use either sunlight or that from 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 with the eye looking into the tube on the grating side. Which wavelength (short-blue or long-red) has a constructive interference closest to the center?
c. Can you think of applications for which you would want to separate light into its spectral components?
d. Shine a laser through a diffraction grating transmission slide at the table and observe the spots forming due to constructive interferences. How will it differ for a blue wavelength?

Station 2. Using a handheld spectroscope to qualitatively analyze the color transmitted through a substance:

a. Look through a spectroscope at white light from within the lab and the natural light outside (the source has to be seen through the slit, do NOT look directly at the sun!!!). Describe any difference in color composition you see.
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 you use here is analogous to the tube you used in Station 1.

Station 3A. Color attenuation, using red, blue, and green LED lights and containers 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 with least attenuation.
b. Test your prediction by shining the LED flashlights through the containers of colored water and comparing it qualitatively to the intensity you see when the light does not propagate through the colored water.

Station 3B. scattering.

a. Shine the laser through the end of an empty tank. Can you see the laser in air?
b. Do the same in a tank filled with pure water. Is it different than air?
c. Shine the light 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 your relate your experience to lasers shooting in space in science fiction movies?

Station 3C. The color we observe remotely.

a. Analogue to deep ocean color: Add about 10-15 drops of 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 or clay into the colored water shine the light into the water. What color is the water?
c. Now repeat this experiment in a tank with a reflective bottom. How is it different from the previous one?

Station 4A. Fluorescence emission of a column with different fluids.

Fluorescence is the name of the phenomenon whereby light absorbed as a given wavelength is emitted at another.

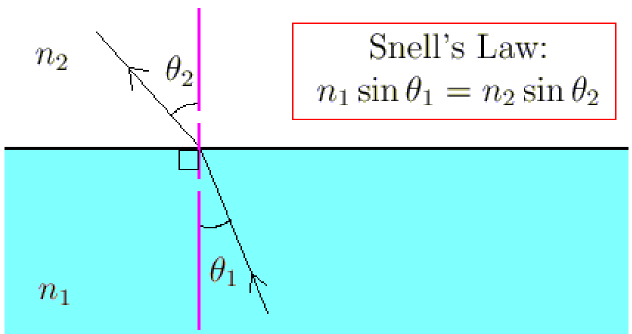
a. Shine white light at the column. Assign a color to each fluid.
b. Shine UV light at the column. How is the color of each fluid different?

Station 4B. Fluorescence emission of spinach extract.

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 ey. 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 5A. Refraction of waves passing through mediums with different transmission properties.



Shine a laser pointer towards the center of a moon-shaped water tank. Observe the angle change due to refraction in the two cases when light propagates from a. air to water and b. water to air.

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?

Station 5B. Refraction.
Put a ruler in a water tank and observe how the angle of entry appears to change in water relative to that in air. Why does the ruler *appear* to bend in the opposite direction of the light ray in the illustration of Snell's law above?

Station 5C. Total internal reflection
a. Through the sides of the tank, shine the laser towards the air from the water side.
b. You will observe that at some angles the light completely internally reflects.
c. Can the same happen when shining light from air to water (as in Station 5A)?

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 5D. Spectral refraction.

Pass white light through a prism.

a. Which light bends the most?
b. What does it tells us about the change of index of refraction of the material the prism is made of as function of wavelength?

Station 5E. 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 refractormeter and read the salinity by looking through the refractormeter.
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:

a. Water or air?
b. Salt water or fresh water?

Station 6. Beer-Lambert-Bouguer lLaw (see appendix for a description of this law).

Materials: two clear tank filled with water, a collimated light source, a light detector, tape, ruler (meter stick), dropper, food coloring (absorbing, dissolved material), Maalox (highly-scattering, non-absorbing material), plastic stirrer to mix after food coloring or Maalox addition, beakers for sampling, 60-mL sampling bottles, labeling pens and tape.

A. Beer-Lambert-Bouguer Law with a scattering material (Maalox): Follow the direction below. Record your results in the attached 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). Record your data in the table below.
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.

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			

B. Beer-Lambert-Bouguer Law with an absorbing material (Food coloring): Follow the direction in the table below. Record your result in the attached 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). Record your data in the table below.
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.

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. What function can describe the curve's shape?
2. Plot ln[I(n)/I(0)] as function of numbers of drops. What function can describe the curve's shape?
3. Using equation 1A in the appendix, 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*) and a measure of concentration *[c]* (use drops).
4. What physical units 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

The Laws 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 18th century scientist observed that:

1. There is a relationship between the degree light attenuate 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 dissolved substances) does attenuation equals absorption. In the 20th 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:

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

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 $I(L)/I_0$. Note that ε may 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, which contributed a lot to optics, in particular the law about reflecti\on 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.

Equipment and supplies

Water tanks
Light sources
Maalox and/or clay
Food coloring
Light meters
Fluorescing column
Spinach extract
UV light source (black light)
Refractometer
Prisms
Diffraction gratings

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.