A SIMPLE PHOTOMETER

Reading: Harris, sections 17:2-17:4.

Instruments are extensions of our senses. They allow us to perform measurements often more sensitively, reproducibly, and conveniently than we could unaided. In this experiment you are going to build a simple photometer. As you know, the intensity of light that passes through a solution containing an absorbing substance is related (through Beer's Law) to the concentration of the absorber. In place of your eye, we will use a phototransistor to gage the intensity of the light. With most modern instrumentation, the measured parameter (in this case, the light intensity) is converted to an electrical parameter, such as current but most often to a voltage.

In general, a transistor might be thought of as a sort of electrical valve or faucet. It controls the flow of current through it. As a faucet regulates flow according to how far you have turned the handle, a transistor controls the current between two wire leads (known as the "source and drain" or the "emitter and collector" depending on the variety of transistor that you are using) by the amount of signal (usually a current in an ordinary transistor; a light intensity for a phototransistor) at a third point (called the "gate" or "base"). The current that flows from the source to drain is proportional to, but is usually much bigger than, the current that is required to operate the gate. Hence, a transistor can amplify a signal.

Rather than measure the current directly with an ammeter, we will convert the current signal to a voltage (which will be directly proportional, but easier to measure than the current.) We do this by letting the current pass through a resistor. Ohm's Law tells us that the voltage that will develop across the resistor is equal to the product of the current and the resistance (V = IR.). We merely use a digital volt meter (DVM) to measure this voltage as in the diagram below.

The phototransistor, battery, resistor, and DVM act as our detector. If we add a lamp and a monochromator (or filter) to isolate one wavelength of light and a cell holder and sample, we have the main components of a photometer or colorimeter. In our case, we will use a three color LED package to produce the light. The voltage that we read on the digital volt meter, DVM, is proportional to the light intensity, or power (P), hitting the phototransistor. So, if we compare the light power (P) passing through our sample at a given wavelength, to the light power (P_o) passing through a cuvette with pure water under the same conditions, we can calculate the transmittance (T) and absorbance (A):

\[ T = \frac{P}{P_o} \quad \text{and} \quad A = -\log\left(\frac{P}{P_o}\right) \]

where P and P_o are the voltages measured for the sample and the water "blank", respectively. We should also note that sometimes a tiny current will pass through the transistor even when no light is hitting the device. This error is known as the "dark current". We must subtract the voltage that develops across the resistor when the transistor is in the dark from the other measured voltages in order to correct for this error.

PROCEDURE

1) Prepare a series of colored solutions with a range of concentrations with a 1-1000x dilution from the
bromocresol green (prepared in base) standard provided for you in the lab. Dilute the indicator with dilute bicarbonate solution to keep the pH above 6.

2) Set up the phototransistor circuit using the Vernier Logger Pro as the DVM. Set the data acquisition time to 10 minutes.

3) Prepare your own home build photometer using LED bulbs, black tape, a disposable cuvette, popsicle sticks, and your detector. Extra points will be awarded for the most creative design.

4) Measure and record the "dark current signal", i.e., the voltage when no light is hitting the transistor.

5) Select a wavelength where the absorbance appears to be the greatest and measure $P_O$ and $P$ for each of the four standards and the unknown solution. You may take a spectra of your indicator solution using an Ocean Optics spectrometer. You may also take an emission spectra of your LEDs by shining your source into the entrance optics of the Ocean Optics. You will use this data to construct a calibration curve (Absorbance vs. concentration) and estimate the concentration of the unknown solution.

6) Estimate the error in your determination of solution concentration. Determine the percent stray light of your instrument.

You will be graded on the following:

1) Design
2) Signal to Noise of the instrument
3) Absorbance Range of the instrument
4) Beer’s Law plot of food coloring.
5) Estimates of analytical error and stray light for your instrument
Calculation of Stray Light

All spectrometers have some stray light. Stray light is light that hits the detector without passing through the sample cell. Since this light never interacts with the sample it will never be absorbed and will cause a constant signal at the detector. Often stray light is proportional to the power of the source.

\[ P_s = XP_o \]  \hspace{1cm} (1)

Considering this added source of light we can compute the observed absorbance at the detector:

\[ A = -\log \left( \frac{P - P_d + P_s}{P_o - P_d} \right) \]  \hspace{1cm} (2)

where \( P \) is the observed power, \( P_o \) is the lamp power, and \( P_d \) is the detector dark signal. The figure below illustrates the effect of 0.5% stray light on the observed absorbance.

The curvature in the signal may be used to calculate the value of \( X \) in equation 1 by fitting observed instrument responses to the Beer-Lambert relationship \( A=\varepsilon b[C] \) modified by \( P_s \).