A SIMPLE PHOTOMETER

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

Instruments are extensions of our senses. They often allow us to perform measurements more sensitively, reproducibly, and conveniently than we could unaided. In this experiment you are going to build a simple photometer. As you know from your reading, 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 photodiode 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.

The light source in this experiment is a three color Light Emitting Diode (LED). By connecting a power source between the common pin to one of the three “color” pins red, green, or blue light is produced. The detector in this experiment is a photodiode which produces a current proportional to light intensity. 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 then use a digital voltmeter (DVM) to measure this voltage as shown in the diagram below.

![Setup of simple photometer](image)

Figure 1. Setup of simple photometer. The detector and light source are inserted into a printed flow cell.
The photodiode and DVM act as our detector. If we add a 3D printed flow cell we have the main components of a photometer or colorimeter. 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 (P₀) passing through a flow cell with pure water under the same conditions, we can calculate the transmittance (T) and absorbance (A):

\[ T = \frac{P}{P_0} \quad \text{and} \quad A = -\log\left(\frac{P}{P_0}\right) \]

where P and P₀ 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 photodiode even when no light is hitting the device. This error is known as the "dark current". We subtract the dark 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 known concentrations by diluting (1-1000x) 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 photodiode circuit using the Vernier Logger Pro as the DVM. Set the data acquisition time to 10 minutes.

3) Build your own home build photometer using LED bulbs, photodiode detectors, black tape, circuit components, and two-phase epoxy. 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 were the absorbance appears to be the greatest and measure P₀ and P for each of the four standards and the unknown solution. You may take a spectra of your indicator solution using an HP 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 BCG solutions.
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.

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

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

\[ A = -\log \left( \frac{P + P_s - P_d}{P_o - P_d} \right) = -\log \left( \frac{P + P_o X - P_d}{P_o - P_d} \right) \]  \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 2 by changing the value of \( X \) until equation 3 fits the expected linear instrument response to the Beer-Lambert relationship \( A = e b[C] \). \( P \) in equation 3 is the observed power at each concentration.

\[ -\log \left( \frac{P - P_o X - P_d}{P_o - P_d} \right) = e b[C] \]  \hspace{1cm} (3)