Josh Michener
BE.309 Lab #3
With Brian Chase

An inverting op-amp was constructed as shown, with $R_3 = 989\Omega$ and $R_4 = 9.94\ k\Omega$. The circuit showed a gain of ~10x, with a maximum of ±10V.

Next, a photodiode and LED were arranged as shown, with R_1 a $2k\Omega$ potentiometer and $R_2 = 983\ \Omega$. The LED and photodiode were aligned such that the LED shone directly on the photodiode. The potentiometer was adjusted until the voltage across R_2 was 0.1V.

The op-amp was then connected to the output of the photodiode. The voltage across R_2 dropped by approximately 50%, which was gained 10x and inverted by the op-amp.

The output of the first op-amp was connected to the inverting input of an AD621 op-amp. The input was again gained by 10x and inverted (recovering the initial orientation). With a constant driving voltage, the noise in the measurement was ±5 mV with a period of 8 ms, or 125 Hz. Additionally, higher frequency noise was observed at lower amplitude.

An identical half-circuit, not including the AD621, was constructed without the LED branch and with a potentiometer to control the gain of the third op-amp. The output of this half-circuit was connected to the non-inverting input of the AD621. The potentiometer was adjusted until the 125 Hz noise was eliminated. This occurred at a resistance of $R_7 = 8.58\ k\Omega$. The amplitude of the remaining noise decreased slightly, to ±3mV.

When both photodiodes were obscured with electrical tape, the offset in the system was approximately 20mV. In comparison to a sample measurement of order 1V, this offset is negligible.

The completed circuit was then used as a spectrophotometer. Solutions with known concentrations of the dye Nile Blue were placed into cuvettes. The cuvette was placed between the LED and photodiode, and the resulting voltage out of the final op-amp was measured. These data are recorded below and plotted in Figure 1.

Sample	Concentration (mM)	Output (V)
A	0	8.0
B	0.001	7.6
C	0.010	6.9
D	0.025	4.8
E	0.050	4.0
F	0.100	3.3
G	0.250	2.9
H	0.500	2.7
I	1.000	2.4
J	2.500	2.0

Table 1

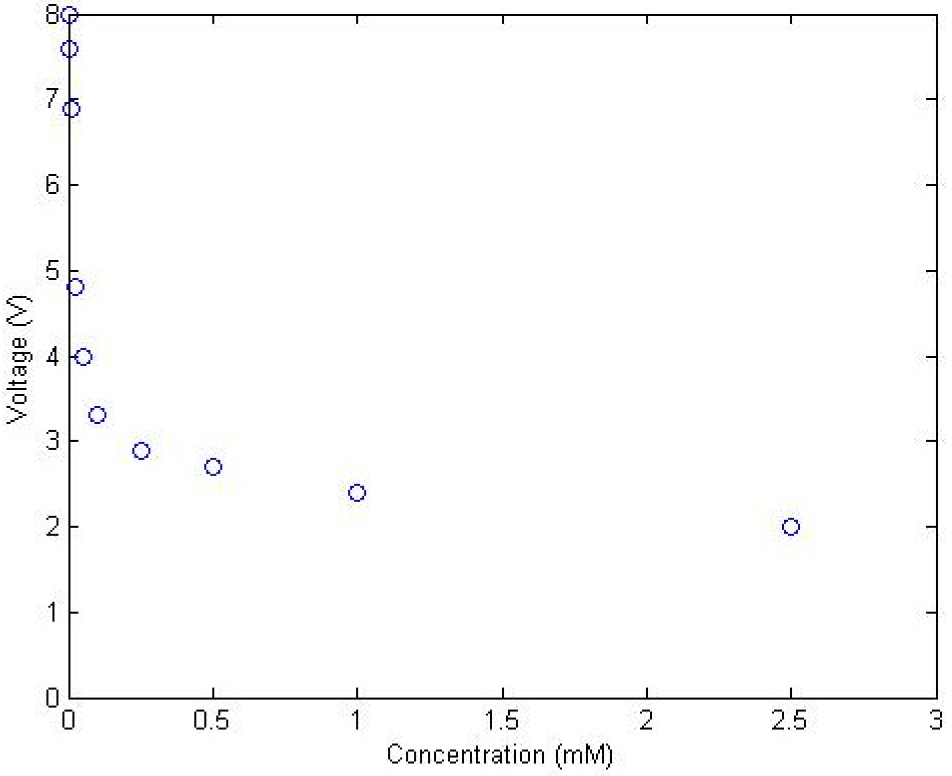

Figure 1

This data was then fitted to Beers' Law, assuming that the output voltage is proportional to the to transmitted intensity minus an offset. As expected, higher concentrations deviated significantly from Beers' Law. Typically, any measurement with an absorbance higher than approximately 1.0 is considered too concentrated for an accurate measurement. The analysis, then, was performed only on the concentrations up to 0.1 mM. The highest concentration gave an absorbance of 1.5, already outside the canonical linear range. The fitted equation was of the form:

$$\log_{10}\left([V_o - V_{offset}] / [V - V_{offset}] \right) = - e\, l\, C \qquad (1)$$

with $V_{offset} = 3.15$ V and $e\,l = 15200\ M^{-1}$. V_o is the voltage of the blank cuvette. The mean squared residual was $R^2 = 0.994$. The fit is shown below, with either the voltage (left) or absorbance (right) plotted vs. concentration.

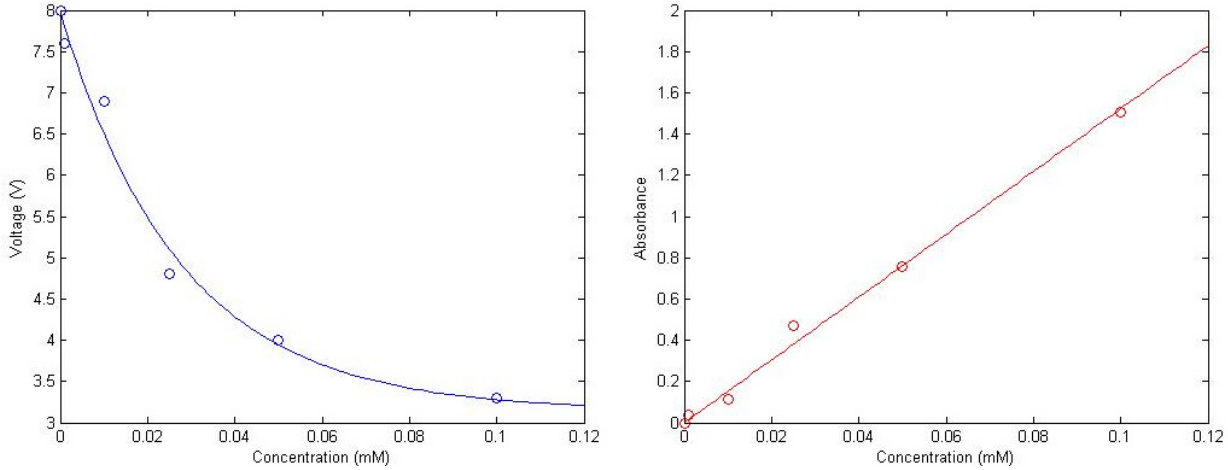

Figure 2

Since *l* was, as is customary, one centimeter, e = 15200 cm/M. The molar extinction coefficient of Nile Blue in ethanol has been measured at various wavelengths.[1] The LED used has an emission maximum at 665nm; the molar extinction coefficient of Nile Blue in ethanol at this concentration is 14500cm/M, in excellent agreement with our measured value.

The main limitation of our photometer lay in reading the output from the oscilloscope. In retrospect, the multimeter may have offered a more precise measurement. Alignment of the LED and photodiode was another source of error. Though a jig was used to maintain alignment, components were not firmly attached to the jig. Variations in alignment would affect the incident light onto the cuvette. Additionally, while adding a second photodiode offered one source of noise correction, isolating the LED and photodiode from the external environment would have been more effective. Noise in the electrical circuit, on the order of ±5mV is negligible in comparison to our measured values. Thus, the main sources of error appear to be methodological.

Finally, deviations from ideality in the LM741 were measured. First, the input offset voltage was measured. A follower was constructed with a voltage divider as the input. The divider was adjusted until the output was nulled. The final input offset voltage was -1.5mV. The datasheet on the op-amp gives 2mV was a typical value.

Next, the bandwidth was measured. An inverting amplifier with a gain of 10 was constructed. A sinusoidal input was connected to the amplifier and the frequency was adjusted until the gain was approximately 7.1. This occurred at 27 kHz. The frequency was further

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[1] Fuh, R. A. "Molar extinction of Nile Blue, ethanol" 6/24/97. <http://omlc.ogi.edu/spectra/PhotochemCAD/abs_html/nileblue(EtOH).html> (10/2/05).

increased until the gain reached 1.0, at 192 kHz. The open circuit bandwidth of the op-amp is given as roughly 1 MHz. The expected bandwidth of our amplifier is unknown.

There was insufficient time to conduct further measurements. However, the slew rate could have been measured by running a triangle wave of varying frequency into an inverting amplifier. The amplitude and frequency of the input could be varied until the output deviates from ideality. According to the manufacturer’s data, this should occur at a slew rate of 0.5 V/µs.