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A Simple Colorimeter for Measuring the Concentration of Multicomponent Food Coloring

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A Simple Colorimeter for Measuring the Concentration of Multicomponent Food Coloring

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Abstract. Built-in instruments are commonly employed in physics experiments. In this case, students are usually unaware of the instrument's fundamental physics. Here we constructed a simple and compact colorimeter. A light-emitting diode (LED) was used as a light source. The light detector circuit consists of a photoresistor, a resistor, and a 9-V battery. During the experiment, we illuminated the solution of food coloring. The transmitted light was measured via the voltage in the resistor of the light detector to obtain the absorbance. The value was then used to determine the concentration of the solution. This instrument has been used to measure a mixture of food coloring's concentration e.g. 1 ml/l Carmoisine and 1 ml/l Ponceau. For this sample, the measurement gave a concentration of 0.97 ml/l Carmoisine and 0.81 ml/l Ponceau. This instrument is simple and appropriate for teaching.

1. Introduction

The experiment in the physics laboratory related to instrument availability. Some instruments are very expensive and complex. Due to the price, especially for advance topics, those instruments are not available in the undergraduate lab. Another concern for learning was that the students just used the instrument to measure a quantity, but they were not aware of the physics behind the instrument. Students can learn the measuring process by understanding the instruments until the results are displayed. There are different functional elements in an instrument, e.g. the primary sensing element, variable conversion element, variable manipulation element and presentation element [1]. The student should also know the instrument's character, e.g. sensitivity and selectivity, to use it properly.

For example, the absorption process can be applied to measure concentration. One can determine the concentration based on the Beer−Lambert law by measuring the light intensity. This process is performed using a light source and a light detector. Lamelas and Swaminathan used laser and photocell to study the relation of absorption and concentrations of food dyes, black ink, and milk [2]. The halogen lamp and digital luxmeter are used as the light source and the light sensor [3]. Recently smartphones were used for the light source as well as the light sensor [4-8].

Other publications show the design of simple colorimeter [9-14]. Those designs are simple, they use LED as a light source. For light detector Jonas et al and Gordon et al used LED and photoresistor, respectively [10-11]. Most articles show the application of the instrument for illustrating the Beer−Lambert law e.g molar absorptivity and concentration measurement.

Those published measurements were performed on a single component species. They focused on the sensitivity, but there is no discussion on selectivity. For measuring concentration the colorimeter is susceptible to the interfering input. Relating to these aspects in the instrument, we construct a simple

colorimeter for measuring the concentration of single species as well in the mixture of two species. Here we show the method and the importance of the selectivity.

A diagram of our colorimeter is shown in Figure 1. The light source circuit consists of a light-emitting diode (LED), a battery E and a variable resistor R_S. As the light detector we use a photoresistor which is connected to a battery E and a resistor R. A voltmeter is used for measuring the voltage on the resistor *V*.

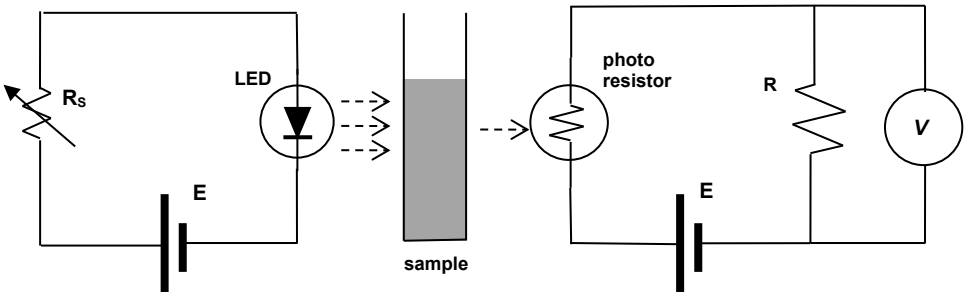

Figure 1. The experiment setup. The sample is placed in a cuvette.

The LED emits light with an intensity of I_0. This light beam causes the resistance of the photoresistor to decrease, in turn, leads to an increase in the voltage *V*. This voltage change is proportional to the light intensity. The absorbing species in the sample attenuates the beam intensity from I_0 to *I*. The absorbance *A* is defined by [9-16]

$$A = -\log\frac{I}{I_0} \quad (1)$$

In the experiment, the sample is the food coloring solution in the water. In this case, when the cuvette is filled with water, the voltage measurement V_0 represents I_0. When the food coloring solution is in the cuvette, the voltage *V* corresponds to the light intensity *I*. All of the voltage measurements are corrected to the background, i.e. the voltage when the LED is off. Using this condition, the sample's absorbance becomes

$$A = -\log\frac{V}{V_0} \quad (2)$$

The absorbance depends on the path length *b* and the concentration *c* of the absorbing species. It follows the Beer's law

$$A = a\,b\,c \quad (3)$$

The absorptivity '*a*' depends on the absorbing species and the wavelength of radiation. For a constant path length, equation (3) becomes

$$A_{ij} = k_{ij}c_i \quad (4)$$

where A_{ij} : absorbance of species *i* at wavelength *j*
k_{ij} : a calibration constant for species *i* at wavelength *j*
c_i : concentration of species *i*

For a mixture of two species X and Y, the absorbance on the wavelength λ_1 and λ_2 are given by [17]

$$A_1 = k_{X1}c_X + k_{Y1}c_Y \quad (5)$$

and

$$A_2 = k_{X2}c_X + k_{Y2}\,c_Y \quad (6)$$

From equations (5) and (6) we can obtain the individual species concentration

$$c_X = \frac{A_1\,k_{Y2} - A_2 k_{Y1}}{k_{X1}\,k_{Y2} - k_{X2}k_{Y1}} \quad (7)$$

$$c_Y = \frac{A_2\,k_{X1} - A_1 k_{X2}}{k_{X1}\,k_{Y2} - k_{X2}k_{Y1}} \quad (8)$$

2. Method

In this experiment, the cuvette was mounted in a close tube. The LED was mounted on one arm of the tube, and the photoresistor was placed on the opposite side of the tube. The nine volts battery E served as a power supply. The variable resistor R_s maintained the operating voltage on the LED. A multimeter was used for measuring the voltage across the 1 KΩ resistor R.

The voltages were measured for water and different concentrations of solution, and these values were used to calculate the absorbance using equation (2). A calibration curve was plotted to obtain the calibration constant *k* using equation (4).

To obtain the absorbance' at different wavelength we used 4 LEDs. These LEDs and their wavelengths are presented in table 1 [13].

Table 1. The wavelength of LED used in the experiment.

LED	**λ (nm)**
blue	425
green	530
yellow	585
red	635

The concentration measurements were performed on a single food coloring i.e. Ponceau 4R and Carmoisine CI 16255, and a mixture of both food colorings. In this case we used equation (7) and (8) to determine individual concentration.

3. Result and discussion

The experiment was performed using the setup presented in figure 1. We measured the voltage based on equation (2) to determine the absorbance. Here we used two food coloring solutions i.e. Ponceau 4R and Carmoisine CI 16255.

Figure 2 shows the absorbance of various concentrations of Ponceau 4R. The absorbance depends on the concentrations. There is a linear dependence of the absorbance to the concentration. According to equation (4), the gradient of this figure gives the calibration constant *k* of Ponceau on a specific wavelength.

For LED yellow (585 nm), figure 2 gives a gradient of (0.102 ± 0.004) l/ml and an offset of (0.002 ± 0.005). Following equation (4) the gradient yields the calibration constant *k* of Ponceau 4R on the wavelength of 585 nm to be (0.102 ± 0.004) l/ml. Using the same calculation, the calibration constant *k* of Ponceau 4R on the wavelength of 530 nm and and 425 nm are (0.51 ± 0.04) l/ml and (1.34 ± 0.08) l/ml, respectively.

The absorbance for various concentrations of Carmoisine CI 16255 is presented in figure 3. The same behaviour was observed on the Carmoisine CI 16255 as in Ponceau 4R. It shows a linear relation of absorbance to the concentration.

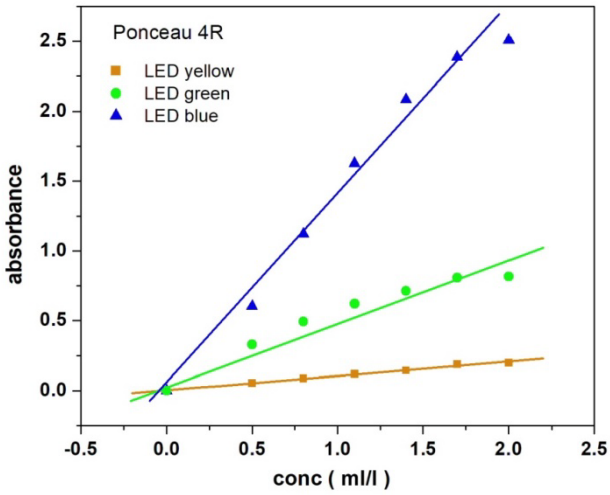

Figure 2. The relation between the absorbance of Ponceau 4R and its concentration using different LED, i.e. yellow (■), green (●) and blue (▲). Solid line is the best fit.

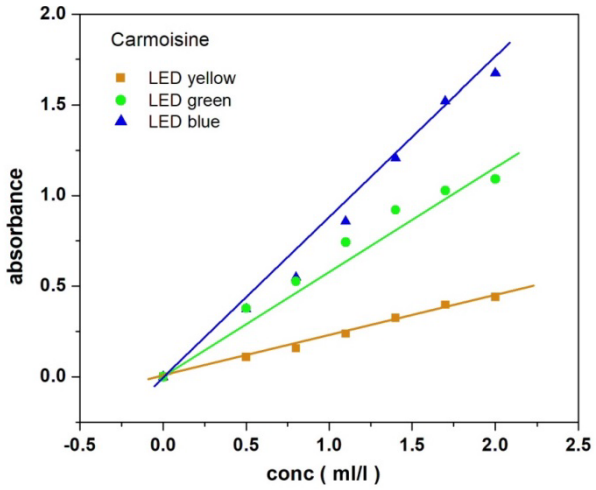

Figure 3. The relation between the absorbance of Carmoisine and its concentration using different LED, i.e. yellow (■), green (●) and blue (▲).

The calibration constants for different wavelengths are presented in figure 4 for Ponceau 4R and Carmoisine CI 16255. It is clear that the calibration constant is unique for the certain molecule as depicted in figure 4. For each wavelength the calibration constant related to the absorptivity of the specific molecule.

Using the calibration constant, we can determine the sample's concentration. Here we have prepared three different 'samples' i.e. 1 ml/l Ponceau, 1 ml/l Carmoisine and two components ‘sample’. The third sample is a mixture that contains 1 ml/l Ponceau and 1 ml/l Carmoisine.

To enhance the selectivity, we have to choose the specific wavelength that gives dominant absorptivity of one species. Based on figure 4.we used wavelength of 425 nm (blue) and 585 nm (yellow) for measuring Ponceau and Carmoisine simultaneously in the sample. At 425 nm, Ponceau’s absorptivity is higher than Carmoisine. In other way around, at 585 nm, Ponceau’s absorptivity is lower than Carmoisine. The calculation of the two-component use equation (7) and (8); the result is presented in table 2.

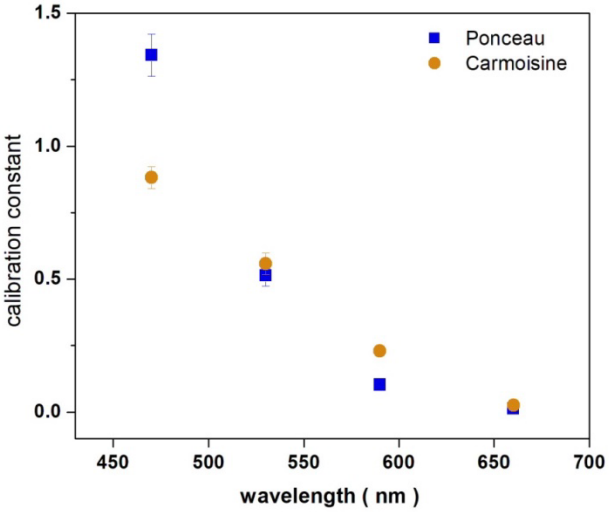

Figure 4. The relation between calibration constant and the wavelength for Ponceau (■) and Carmoisine (●). Solid line is the best fit.

Table 2. The measurement concentration of sample using simple colorimeter .

Component	Sample	Concentration (ml/l)	
		Ponceau	Carmoisine
Single	1 ml/l Ponceau	0.86	0.01
Single	1 ml/l Carmoisine	-0.05	0.92
Double	1 ml/l Ponceau and 1 ml/l Carmoisie	0.81	0.97

Table 2 show the measurement for the sample of pure 1 ml/l Ponceau the calculation gives the concentration of Ponceau and Carmoisine to be 0.86 ml/l and 0.01 ml/l, respectively. The Ponceau concentration is 15% lower than the prepared concentration. The concentration of Carmoisine is very low 0.01 ml/l as expected to be zero.

A better result is observed in the measurement of the pure 1 ml/l Carmoisine sample. Here the measurement gives the concentration of Ponceau and Carmoisine to be -0.05 ml/l and 0.92 ml/l, respectively.

We measure a mixture containing 1 ml/l Ponceau and 1 ml/l Carmoisine for two species sample. In this case the results are 0.81 ml/l and 0.97 ml/l for concentration Ponceau and Carmoisine, respectively. The result is appropriate for this experiment. Using this simple setup, the discrepancy between the measurement and the expected concentration is relatively low. The calculation is based on equation (7) and (8) that related to the calibration constant. Here the calibration constants are obtained from the gradient of figure 2 and 3. A close observation shows that the data points are not perfectly in the linear line.

Actually LED is not a monochromatic light. It leads to the broadening of the absorption spectrum [10]. This system is prone to the interfering molecule. This factor contributes to the deviation from the expected value.

This experiment is suitable for teaching. As the light source, LED is cheap and long life. The use of food coloring is safe; it is not a hazardous material. Overall the student can observe each part of the setup and its function directly. The student can also learn different topics, e.g., electronic circuit, absorption, and measurement method.

4. Conclusion

We have constructed a simple colorimeter to study the food coloring concentration measurement method. Here the light intensity is represented by the voltage at a fixed resistance on the photodetector circuit. Study on the absorptivity has been performed using different food colorings as well as different wavelengths. The results show that absorptivity is unique. It depends on the species and wavelength. The calibration constant is obtained for a specific wavelength by measuring the absorbance. The setup is able to determine the concentration of two species in the sample.

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