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Teaching Beer's Law and Absorption Spectrophotometry with a Smart Phone: A Substantially Simplified Protocol

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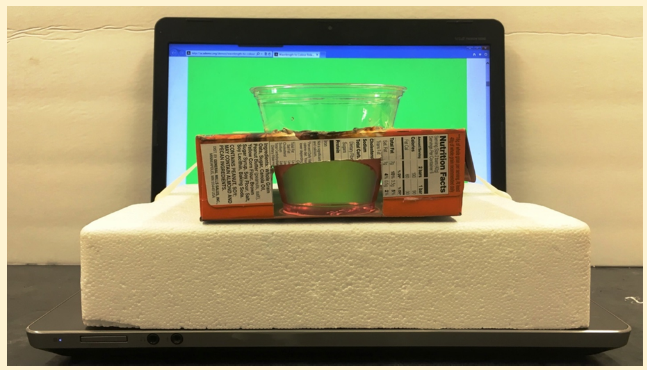
Supporting Information

ABSTRACT: A very simple protocol for teaching Beer's Law and absorption spectrophotometry using a smart phone is described. Materials commonly found in high school chemistry laboratories or even around the house may be used. Data collection and analysis is quick and easy. Despite the simple nature of the experiment, excellent results can be achieved.



KEYWORDS: *High School/Introductory Chemistry, First Year Undergraduate/General, Analytical Chemistry, Laboratory Instruction, Hands-On Learning/Manipulatives, Spectroscopy, UV-Vis Spectroscopy*

INTRODUCTION

Quantification of analyte concentration using absorption spectrophotometry via Beer's Law analysis is an important facet of undergraduate and Advanced Placement Chemistry curricula.[1] Given the limited resources in many high schools and colleges, it is not surprising that several authors have described how to build simple and inexpensive absorption spectrophotometers and colorimeters.[2−4] Such instruments are generally simple in design, but their construction is often somewhat involved, requiring the use of light emitting diodes, photodiode detectors, and the like. In 2010, Scheeline reported how a cell phone camera can be used in spectrophotometric analysis.[5] This protocol eliminated the need for a photodetector, but nevertheless remained relatively complicated. Reports have also appeared in this *Journal* that describe how cell phones can be used to conduct colorimetric[6−11] and fluorescence[12] analyses. These experiments further simplified the process, allowing Beer's Law experiments to be conducted in almost any high school laboratory. However, because these experiments require a somewhat sophisticated analysis of digital photos, these experiments involve drawbacks for those looking for a simplified approach. Furthermore, these experiments do not allow students to explore the process of light absorption by sample that occurs in absorption spectrophotometry.

The experiment presented here allows students to conduct Beer's Law analysis with a cell phone camera. The protocol was developed with simplicity in mind. The setup is very simple, the data collection is fast and easy, and the data analysis is substantially streamlined. Nevertheless, the process of conducting the experiment allows students to quantitatively and qualitatively explore concepts and equations involved in absorption spectrometry.

BACKGROUND

In absorption spectrometry, light is directed through a sample and the fraction of light that passes through the sample is measured (Figure 1).

The amount of light absorbed, or the absorbance, A, is defined as

$$A = -\log\left(\frac{I}{I_0}\right) \tag{1}$$

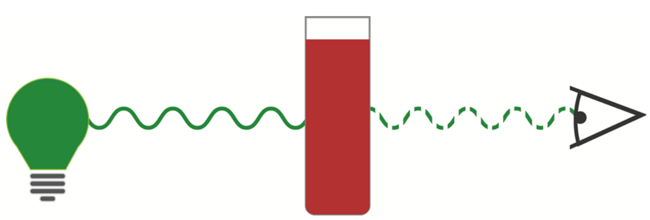


Figure 1. Green light is shined through a red solution and the amount of light transmitted is detected.

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where I is the intensity of light transmitted through the sample and I_0 is the intensity of light transmitted through a blank. It is useful to use a color wheel (Figure 2) to estimate the color of light that is absorbed by a particular chemical species in solution.[13] This approximation is done by noting the color on the wheel opposite the observed color of the compound. For example, if a particular species appears red in solution, it probably absorbs green light very well. The predictions made using the color wheel are not absolute. Its use is complicated by the fact that our eyes are not equally sensitive to all colors of light, in addition to other factors.[13]

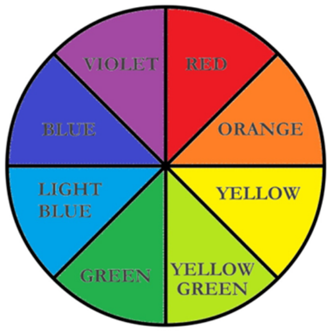

Figure 2. A color wheel used to estimate the color of light absorbed by a solution of a certain color.

In solutions that are sufficiently dilute, absorbance depends linearly on analyte concentration, c:

$$A = \varepsilon bc \tag{2}$$

where ε is the molar absorptivity of analyte and b is the length of sample through which light from the source travels. Equation 2 is also known as Beer's Law. This relationship is useful in determining the concentration of analyte samples. To do so, the absorbance of a solution of unknown concentration is compared to a series of solutions of known concentration.

The experiment presented here describes how to conduct absorbance measurements and Beer's Law analysis using a remarkably simple protocol. A cell phone application (herein called the RGB analyzer) capable of determining average RGB value of images in the camera view, in real time, is used as the light detector.[14] Either light reflected from colored construction paper or light from a computer screen is used as a light source.[15] Cuvettes, test tubes, or even clear plastic cups can be used to hold samples.

■ EXPERIMENTAL SETUP

More detailed information and helpful tips may be found in the Supporting Information. A cardboard box (herein called the sample box) was constructed to house samples (Figure 3). The sample box was constructed to allow light to pass through the sample and to be measured.

Figure 3. A cardboard box cut to fit sample. Note the rectangle cut in the front of the sample box to allow the cell phone camera to detect light passing through the sample. The entire back panel of the box has been removed to allow light from a source to pass through the sample.

Five solutions of known concentration (0.10−0.50 M) of $CuSO_4$ were prepared. Red construction paper was placed behind the sample box, which was arranged such that the construction paper could be viewed through the sample. It should be noted that using the color wheel, it is predicted that orange light should be absorbed best by the light blue colored $CuSO_4$ solutions. However, the color wheel is approximate: $CuSO_4$ absorbs substantially more red than orange light.[13] Also, it is pedagogically more straightforward to use only red, green, or blue construction paper (or light source) when using the RGB analyzer. The box was arranged such that room light reflected off the construction paper could pass through the sample and be detected by the cell phone (Figure 4). The box was secured in the same orientation throughout the experiment.

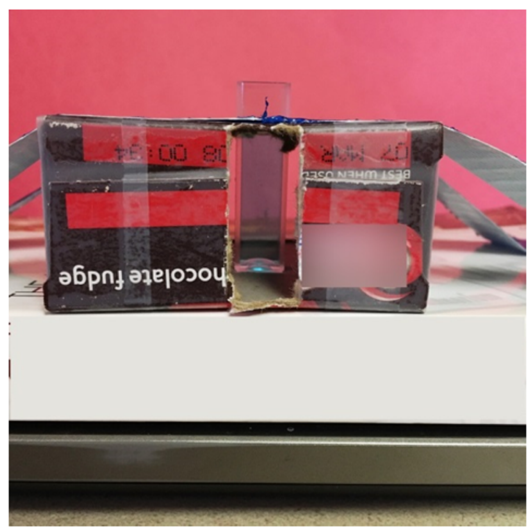

Figure 4. Sample box placed on top of a book and secured in place with tape. Note that the red construction paper is visible through the sample and hole on the front of the box.

The RGB analyzer application was opened on the cell phone. A cuvette filled with water (the blank) was placed in the sample box, and the R value of light (designated I_0) passing through the blank was recorded (Figure 5, left). In a similar manner, the R values for the samples of known concentration of $CuSO_4$ were determined (Figure 5, right). The absorbance of each sample was determined using eq 1.

■ HAZARDS

Copper sulfate is a respiratory irritant and harmful if swallowed.

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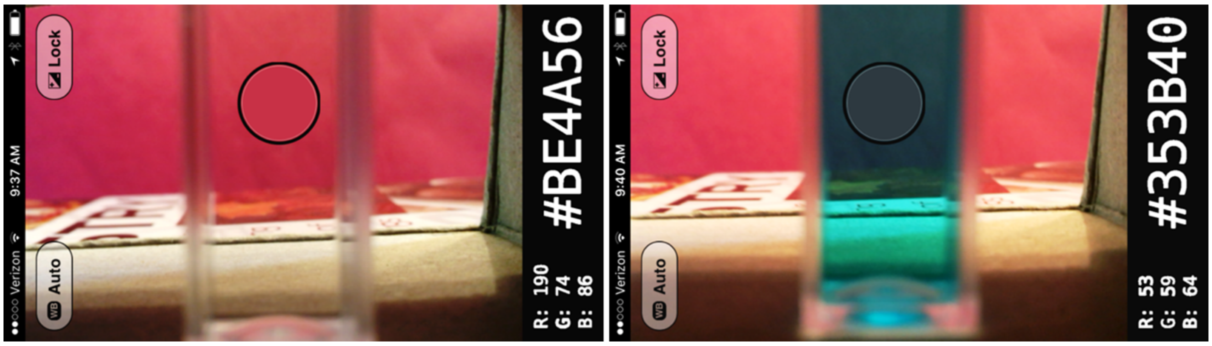

Figure 5. View of blank (left) and sample of 0.50 M $CuSO_4$ (right) through the RGB analyzer on a smart phone. The application records the average R, G, and B values of the pixels within the circle (see lower right-hand corner of each image). Given the R values for the blank (190) and the sample of $CuSO_4$ (53), eq 1 yielded an absorbance of 0.554 for the sample of $CuSO_4$.

RESULTS

With the use of this procedure, plots of absorbance of $CuSO_4$ solutions vs concentration routinely yielded a straight line relationship (Figure 6). Linear fits to the data collected over several trials typically yielded R^2 values of 0.985 or higher. Similar results were achieved when light from a computer screen was used as a light source (see Supporting Information). Likewise, comparable results were achieved using different chemical species such as food dyes (see Supporting Information). It is also interesting to note that this experiment has worked just as well using test tubes or even clear plastic cups to hold sample (see Supporting Information). The abstract image shows a possible setup for this experiment using a clear plastic cup to hold sample, a computer screen as a (green) light source, and red food dye as analyte.

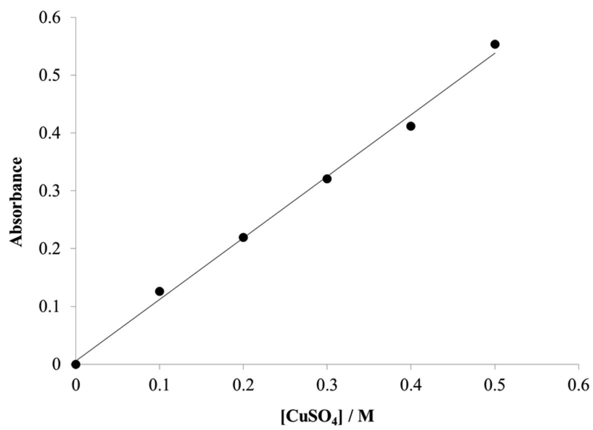

Figure 6. Representative plot of absorbance of solutions of known concentration of $CuSO_4$. R^2 = 0.996 for the linear fit.

CONCLUSION

The experiment reported here provides a simple way to have students explore absorption spectroscopy with equipment routinely found in high school chemistry laboratories. The setup is simple, data collection is fast, and data analysis is straightforward. This experiment can be completed with excellent results using materials routinely found at home: clear plastic cups, cardboard boxes, construction paper, a smart phone, and food dye. As a result, the protocol described herein should be quite useful to high school chemistry teachers and instructors who work with limited funds but wish to introduce absorption spectrometry into their classes. This experiment also has the potential to provide a solid experience in a distance learning environment, which has proven to be somewhat challenging for chemistry courses.[16]

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00844.

Additional sheet providing greater detail on experimental setup, helpful tips on how to carry out this experiment, and additional data collected under different experimental conditions (PDF, DOC)
Student worksheet (PDF, DOC)

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Notes

The authors declare no competing financial interest.

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