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A Simple, Small-Scale Lego Colorimeter with a Light-Emitting Diode (LED) Used as Detector

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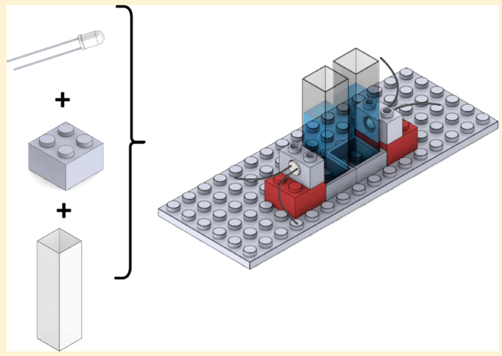
Supporting Information

ABSTRACT: This article describes how to construct a simple, inexpensive, and robust colorimeter from a few Lego bricks, in which one light-emitting diode (LED) is used as a light source and a second LED as a light detector. The colorimeter is suited to various grades and curricula.



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Spectroscopy is part of all chemistry syllabi. Spectrophotometers, as other instruments used in modern chemistry, are generally black-box systems that are less suited as learning tools at the introductory level, when trying to convey fundamental concepts.[1] In addition, they are costly.

Colorimetry is an intuitive and simple method of demonstrating basic spectroscopic principles, as well as having a range of useful application within a number of fields.[2] Several simple and inexpensive colorimeters have been reported,[3−15] employing various materials (e.g., film canisters, well-plates, measuring cylinders, mobile phones, etc.) and using semiconductor technology (light-emitting diodes and various circuitries). Light-emitting diode (LEDs) are inexpensive, long lasting, and emit light over a limited range of wavelengths, typically 20−30 nm around the peak value (λ_{max}).[6,12] They are suitable when finding an unknown concentration based on a calibration curve and for illustrating the Beer−Lambert law, including estimates of molar absorptivity.

Herein, we report how to construct a colorimeter that can be assembled in 5 min and costs less than $4 (apart from the millivolt meter and battery). It has two particular features:

(1) A LED is used as the light detector.

(2) It is made from a few standard Lego bricks.

Lego bricks provide an accurate and robust alignment of the light source and detector, while still being flexible. This allows students to easily explore the relationship between transmittance and path length. The inherent flexibility of the Lego bricks has previously been exploited to construct model instruments[13,14] as well as to demonstrate chemical structures.[13]

■ COLORIMETER DESIGN

The complete Lego colorimeter is shown in Figure 1. The top of two Lego bricks (2 × 2) are cut off to accommodate the cuvettes. Each LED is firmly pressed into a Lego brick with hole (2 × 1 with hole). A 3 V source (2 × 1.5 V batteries) wired in series with a resistance appropriate to the particular LED powers the colorimeter. A second LED is used as a detector. Measurements are made using a millivolt meter (e.g., digital

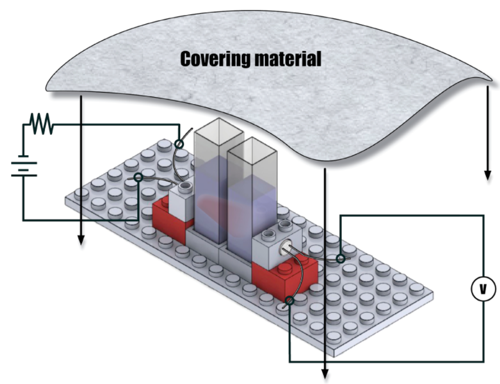

Figure 1. Complete Lego colorimeter.

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multimeter) connected directly across the detector LED and are typically in the range 10−1000 mV. A piece of a black plastic bag is used as a cover to avoid stray light. We use solutions of $Cu(NO_3)_2$ in the range 0.010−0.70 M to demonstrate the Beer−Lambert law. However, food coloring could also be used. Further information is available in the Supporting Information.

Some students prefer modern instruments and find small-scale and simple technology inferior; however, we found that most students appreciate the transparency of the experiment and enjoy constructing with Lego bricks.

Standard Lego bricks can easily be moved around, while still maintaining accurate positioning and alignment, making the use of the colorimeter flexible. A standard 5 mm LED fits tightly and precisely into a brick with hole; the colorimeter is therefore not subjected to the problems of changes in alignment of the LED that would result in unstable readings.[8]

The use of a piece of black plastic and not embedding the experiment in a box makes the technology more transparent and invites discussion into stray light. However, suitable covering material varies depending on light conditions at different locations.

The use of a LED as a detector may come as a surprise to some readers; nevertheless, this has been well-known for several decades.[16] A LED emits light at a characteristic wavelength (actually over a narrow band of wavelengths around the characteristic value) when a current is applied. However, a LED will also produce a voltage if exposed to light with a similar or shorter wavelength than the characteristic. In this experiment, our light detector is a red LED, which is sensitive to all colors in the visible spectrum.

The number of required electrical parts is kept to a minimum and consists of two LEDs, a few wires, a 3 V battery, a single resistor, and a millivolt meter. The resistor is needed to bring the voltage to within the optimal working range of the LED. Further information may be found in Supporting Information.

The colorimeter may be used to explore concepts such as transmittance, absorbance, and finding an unknown concentration after making a calibration curve. It is suitable for exploring the Beer−Lambert law, in particular absorbance as a function of concentration and absorbance as a function of cell length. A reasonable estimation of molar absorptivity may be obtained.

We believe transmittance is more intuitive than absorbance as a first introduction; thus, our students measure percent transmittance

$$\%T = \frac{V_{\text{solution}}}{V_{\text{water}}} \times 100\%$$

where V_{solution} is the voltage measured when the solution is used and V_{water} when water is used. Absorbance is then calculated from transmittance.

HAZARDS

A knife or hacksaw is used to cut the 2 × 2 Lego bricks. If the brick is held with pliers, no hazard is involved. The solutions used for the measurements must be handled according to safety instructions. Alternatively, one can use food coloring. Copper nitrate as a solid is an oxidizing agent, harmful if swallowed and toxic to aquatic life as well as causing skin irritation and damage to the eyes. Here it is used in dilute solution (less than 1 M). Still, it should be handled with care and not be released to the environment.

ACTIVITY

The students start by constructing the Lego colorimeter. They then measure output voltage for water and the different solutions and use these values to calculate percent transmittance. The experiment is run with both a single cuvette of solution and with two cuvettes. Finally, absorbance is calculated and plotted on a graph. We also let the students use several different LEDs (as these are easily substituted in this Lego-colorimeter). In Figure 2, absorbance of red light (λ_{max} = 635 nm) and orange light (λ_{max} = 591 nm) as functions of Cu^{2+} solution concentration is given for light passing through one and through two cuvettes. The plots of absorbance are close to linear (r^2 > 0.998 for all curves) over the whole concentration range investigated (0.010−0.70 M).

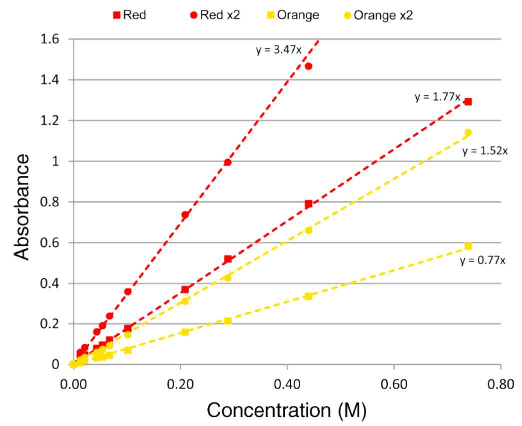

Figure 2. Absorbance of light from a red LED (λ_{max} = 635 nm) and an orange LED (λ_{max} = 591 nm) through one and through two cuvettes, as functions of concentration of Cu^{2+}. Linear fits to the data are shown, together with the slopes of these fits.

In Figure 3, the ratio between absorbance through two cuvettes (20 mm cell length) and through one cuvettes (10 mm cell length) is shown as a function of concentration for red and orange LED light. From the Beer−Lambert law, a ratio of 2.0 is expected. The values found are close to 2.0 other than for very low concentrations where the value falls to about 1.7.

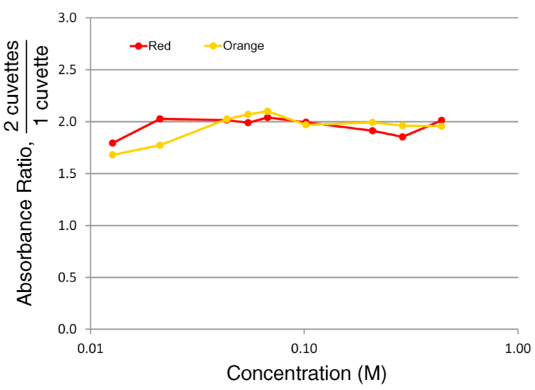

Figure 3. Ratio between absorbance of light passing through two cuvettes (20 mm path length) and through one cuvette (10 mm path length), for a red LED (λ_{max} = 635 nm) and an orange LED (λ_{max} = 591 nm), as functions of concentration of Cu^{2+}.

The molar absorptivity is calculated for all the results and is shown in Figure 4. The molar absorptivity of $Cu(NO_3)_2$ for a red LED light with (λ_{max} = 635 nm and dominant wavelength 626 nm) is 1.75−1.80 M^{-1} cm^{-1} for concentration 0.040−0.70 M, and increases somewhat for lower concentrations. These results provide a reasonable estimate of molar absorptivity and can be compared with results from two standard instruments (a Hitachi U-1900 and a Shimadzu UV−vis 160A) for the same range of concentrations. For both instruments, molar absorptivity is 1.61 M^{-1} cm^{-1} at 620 nm, 1.83 M^{-1} cm^{-1} at 625 nm, 2.03 M^{-1} cm^{-1} at 630 nm, and 2.27 M^{-1} cm^{-1} at 635 nm (standard deviations 6−10%) for 0.040−0.70 M. Interestingly, the molar absorptivity was found to increase by about 15% at 0.020 M (at all wavelengths), as is also the case for the Lego colorimeter and is probably due to the high transmission at these low concentrations (>90%).

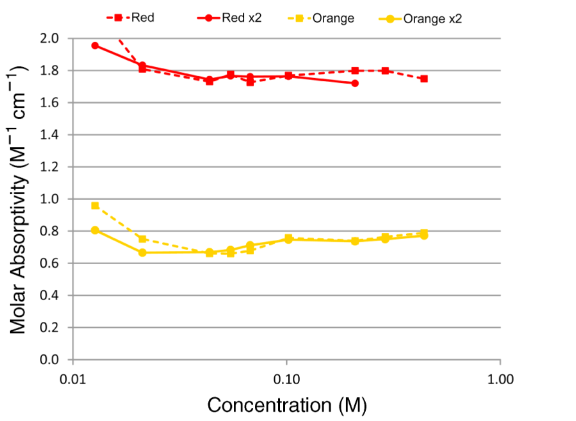

Figure 4. Molar absorptivity for light passing through one cuvette (10 mm path length) and through two cuvettes (20 mm path length), from red LED (λ_{max} = 635 nm) and orange LED (λ_{max} = 591 nm), as functions of concentration of Cu^{2+}.

SUMMARY

A simple, cost-effective colorimeter constructed of Lego bricks, employing one LED as light source and a second LED as a detector (light-voltage sensor) is presented. The results with this colorimeter illustrate the Beer−Lambert law.

ASSOCIATED CONTENT

Supporting Information

Instructor and student notes with supplementary experimental details. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Bauer, S. H. Scientific Literacy vs. Black Boxes: With Reference to the Design of Student Laboratory Experiments. *J. Chem. Educ.* **1990**, *67*, 692−693.
(2) Anzalone, G. C.; Glover, A. G.; Pearce, J. M. Open-Source Colorimeter. *Sensor.* **2013**, *13*, 5338−5346.
(3) Jaffar, M.; Zahid, Q. A Low-Cost Precision Colorimeter. *J. Chem. Educ.* **1988**, *65*, 1099−1100.
(4) Crump, J.; Sandwick, R. K. A Simple Microwell Colorimeter for Use in an Introductory Chemistry Lab. *J. Chem. Educ.* **1994**, *71*, A199−A200.
(5) Hamilton, J. R.; White, J. S.; Nakhleh, M. B. Development of Low-Cost Four-Color LED Photometer. *J. Chem. Educ.* **1996**, *73*, 1052−1054.
(6) Mozo, J. D.; Galán, M.; Roldán, E. Application of Light Emitting Diodes to Chemical Analysis: Determination of Copper in Water. *J. Chem. Educ.* **2001**, *78*, 355−357.
(7) Gordon, J. S.; Harman, S.; Weiss, K.; Pettegrew, B. A. Microscale Spectrophotometric Determination of Water Hardness. *J. Chem. Educ.* **2001**, *78*, 1089−1090.
(8) Gordon, J. S.; Harman, S. A Graduated Cylinder Colorimeter: An Investigation of Path Length and the Beer-Lambert Law. *J. Chem. Educ.* **2002**, *79*, 611−612.
(9) Gordon, J. S.; James, A.; Harman, S.; Weiss, K. A Film Canister Colorimeter. *J. Chem. Educ.* **2002**, *79*, 1005−1006.
(10) Gordon, J.; Tye, S. A LED Microtiter Plate Reader. *J. Chem. Educ.* **2005**, *82*, 903−904.
(11) Kennepohl, D.; Connors, M. An Inexpensive Mini-Colorimeter for Undergraduate Science Laboratories. *Aust. J. Educ. Chem.* **2009**, *70*, 38−41/45.
(12) Scheeline, A. Teaching, Learning, and Using Spectroscopy with Commercial, Off-the-Shelf Technology. *Appl. Spectrosc.* **2010**, *64*, 256A−268A.
(13) Campbell, D. J.; Miller, J. D.; Bannon, S. J.; Obermaier, L. M. An Exploration of the Nanoworld with Lego Bricks. *J. Chem. Educ.* **2011**, *88*, 602−606.
(14) Albert, D. R.; Todt, M. A.; Davis, H. F. A Low-Cost Quantitative Absorption Spectrophotometer. *J. Chem. Educ.* **2012**, *89*, 1432−1435.
(15) Kehoe, E.; Penn, R. L. Introducing Colorimetric Analysis with Camera Phones and Digital Cameras: An Activity for High School or General Chemistry. *J. Chem. Educ.* **2013**, *90*, 1191−1195.
(16) Mims III, F. M. *Light Emitting Diodes*; Howard W. Sams & Co.: New York, 1973; pp118−120.