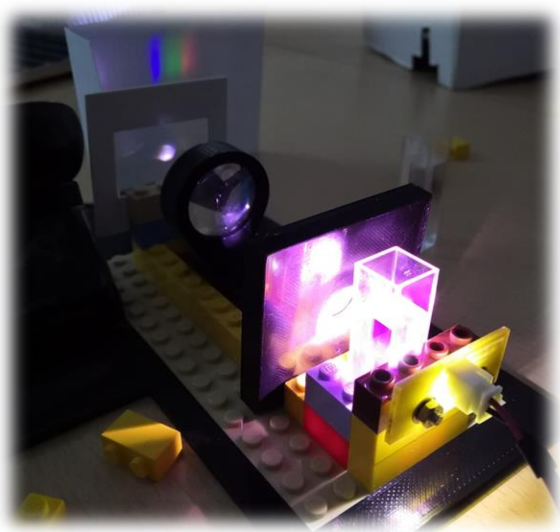
Building spectrophotometer using LEGO



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Appropriate for students aged between 20 - 25

Length

Preparation and introduction: 120 minutes

Implementation: 60 minutes

Closing: 30 minutes

Hypothesis

With regard to the principles of absorption spectroscopy, the Beer–Lambert law is derived by considering that the loss of light traversing an absorbing material is proportional to the amount of light present initially, $-dI/dx \propto I$. This is shown directly using the first configuration of the experiment and also offers an opportunity to explain why exponential functions are so common in physical sciences.

Key vocabulary

Spectroscopy, Physical Chemistry, Hands-On Learning/Manipulatives.

Objectives

- ✓ *Understand the principles of absorption spectroscopy, together with the concepts of absorbance and molar extinction coefficient.*
- ✓ *Provide a visual and quantitative validation of the Beer–Lambert law.*
- ✓ *Develop their scientific inquiry skills.*
- ✓ *Know the meaning of spectrophotometer, absorption spectrum, Beer-Lambert law concept.*

Equipment and material

No	Material/equipment	Quantity	Role in the experiment
1	Bright white-light LED	1	To be used as a light source.
2	Slit	1	The slit will be constructed by the gap between two interlocking bricks.
3	Plano-convex lens	1	Glue to mount that can be translated on an “optical rail”.
4	Dispersing element	1	A low-cost polymer transmission grating, diffracts the light at an angle that is wavelength dependent, thus dispersing the colours when viewed on a screen.
5	Webcam	1	A monitoring device used to capture an image (either fluorescence or the dispersed light projected on a screen).
6	Interlocking bricks		To build a housing and mount for various components.
7	1 × 1 cm plastic cuvette		To hold the samples and place them in the light path.
8	Samples	1-5	

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Introduction

With this experiment, you will be able to build with students a reconfigurable visible spectrometer using interlocking bricks (LEGO). This can be used for the practical demonstration of the Beer−Lambert law by monitoring the fluorescence emitted from the sample as the light passes through. The instrument will allow for the recording of an absorption spectrum of a sample that is comparable to a commercial UV− vis spectrometer.

Absorption spectroscopy is an essential technique that gives access to information about physical properties of molecules related to their geometric and electronic structure and is often used to determine the concentration of molecules in, for example, kinetics experiments or as a sensitive probe of the influence of an environment. The theory of absorption spectroscopy is generally introduced through the derivation of the Beer− Lambert law, which then leads to concepts of absorbance and the molar extinction coefficient.

In this laboratory experience, students will gain basic knowledge on absorption spectroscopy with a simple, low-cost instrument using interlocking bricks and a few optical components that can (with minimal changes) perform as both a spectrophotometer and fluorometer. The spectrometer allows the collection of semiquantitative data, requiring both data analysis and calibration, as these are essential components of practical spectroscopy.

Experiment instructions

General

- Begin the lesson by explaining the purpose of the experiment and the materials that will be used.
- Explain the fundamental theory of Spectroscopy, spectrophotometer, Beer− Lambert law, absorption spectrum and molar extinction coefficient.
- Proceed to the construction of the LEGO spectrophotometer following the instruction in the "Builder's Booklet". If you have materials for more than one spectrophotometer, students can be divided into groups of 4-5 persons.
- Proceed to the measurement of two/three spectra samples. Each group can work with the same sample or with different ones.

Steps to follow

- Follow the instruction in the "Builder's Booklet" (see attachment at the end of the document).

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Safety measures

No	Risk	Safety measure
1	Fluorescein	Minimal risk at these low concentrations: - For disposal, rinse down with plenty of water. - In case of eye contact: rinse with water - If swallowed: Rinse mouth with water and drink plenty of water
2	Potassium permanganate	Minimal risk at these low concentrations: - For disposal, rinse down with plenty of water. - In case of eye contact: rinse with water - If swallowed: Rinse mouth with water and drink plenty of water

Evaluation

- Each student/group writes a report of the Lab Experience, including Hypothesis, Methods, Processes and Observations.
- Alternatively, they can prepare a talk/PowerPoint presentation about their experience to introduce the topic to other students or the teacher.

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Builder's Booklet

DETAILED CONSTRUCTION OF SPECTROMETER

The base was a 24 × 16 Lego® baseplate (3334). For the light source, we used a bright white-light LED (5 mm, 15° viewing angle, OVLEW1CB9, TT Electronics) mounted inside the central hole of a Lego® Technic 1 × 4 brick (3701). Three AA batteries in series (4.5 V total) and two 33 Ω (33R0) resistors in series were used to drive the LED. These were mounted on a small PC board with holes to allow the board to be screwed into the Technic 1 × 4 brick (3701) (see Figure 1). Note, however, that the LED fit is snug and does not need the additional fixing screws. The batteries are contained in a battery holder (black box in Figure 1a and b).

The slit is simply constructed by the gap between two 1 × *n* bricks. We trialled a variable slit with micrometre resolution and also constructed slits from pairs of razor blades in a 3D-printed holder, but ultimately found comparable and more consistent performance using the Lego® slit.

The lens is a plano-convex 50 mm focal-length lens (LA1255-A, Thorlabs) that is glued in a 3D-printed mount. The bottom of the mount has the dimensions of a 2 × 2 Lego® brick. To alter the focus, the lens is mounted on an optical rail that was constructed from a pair of 2 × 4 Lego® flat tiles (87079) placed end-to-end and guided by placing a pair of 1 × 4 Lego® brick (3010) on either side of the flat tiles. A technical drawing of the lens mount is shown in Figure 2. The mount was printed using PLA and the cost of printing a single mount <£1. Note that the lens can be glued directly onto a 2 × 2 Lego® brick (3003), but this was less sturdy, especially for use in an undergraduate laboratory. The core requirement for the lens is that it is at the height of the LED which is 33.6 mm (taking into account the 2 × 4 L Lego® flat tiles (87079) in the optical rail).

As a dispersing optic, we chose to use a low-cost polymer transmission grating (1000 lines/mm, Sciencestore), which was mounted on a 23 × 34 mm card and simply blu-tacked onto a 1 × 4 Lego® brick (3010). In principle, this can be permanently glued on, but we considered it useful for the students to see how light diffracts and have left it to the student to insert the optic in the correct orientation.

As a sensor, we opted to use a simple webcam (Logitech C270), which was used to capture an image (either fluorescence or the dispersed light projected on a viewing screen). The focus of the webcam needed to be altered for the best resolution. For this we removed the front cover, which give access to an adjustable lens in front of the CMOS sensor (1920 × 1080 pixels). This only need to be done once and should not be adjustable by the students as the distance to the screen/fluorescence cuvette can be defined in the experiment.

Finally, the liquid samples were held in a standard 1 × 1 cm plastic cuvette and placed in the light path as described below. To capture images of sufficient quality, a 'light-tight' box is constructed from Lego® bricks around the detection area with an open area made for the webcam to offer a view inside the box.

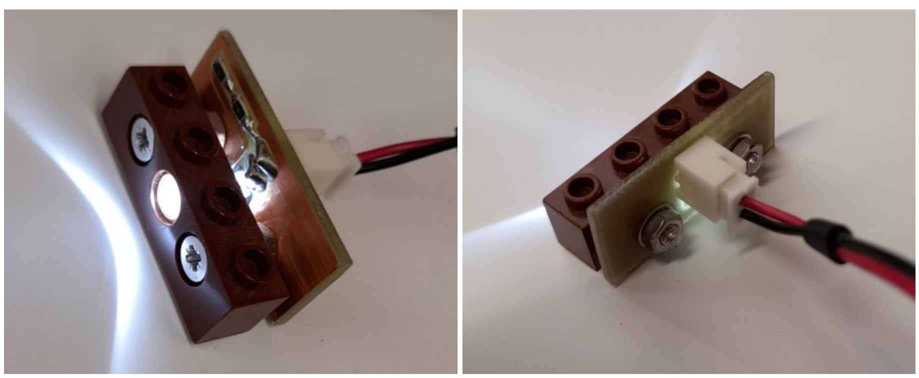


Figure 1: Photo of LED mounting

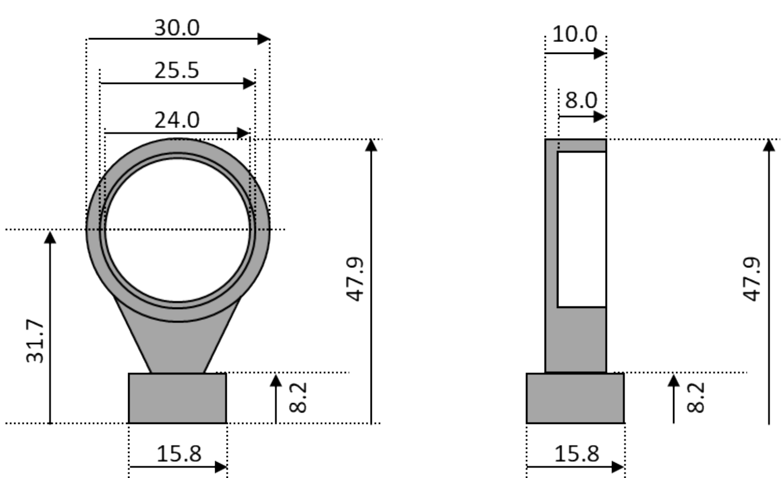


Figure 2: Technical drawing of lens mount. All dimensions are in mm.

DETAILED CONSTRUCTION OF SPECTROMETER

The construction of the two different set-ups is detailed below using diagrams. The basic structure is shown below:

Key:

Yellow = bricks;

Pale pink = flat tiles for optical rail (only require for absorption spectrometer).

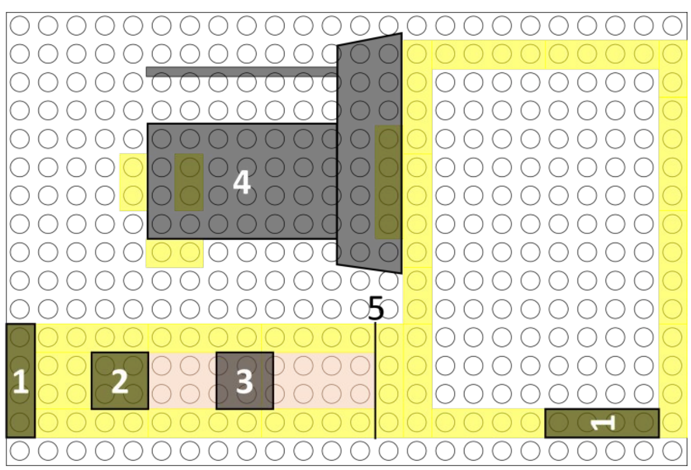
1 = LED brick (can be in two places for differing experiments (see below);

2 = sample holder (cuvette) (for absorption spectrometer, different in fluorescence imaging (see below);

3 = lens with mount (only require for absorption spectrometer);

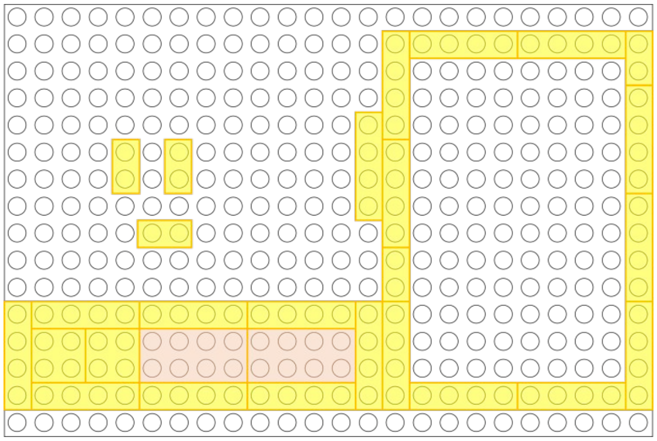
4 = webcam (same place for both experiments);

5 = grating (only require for absorption spectrometer).

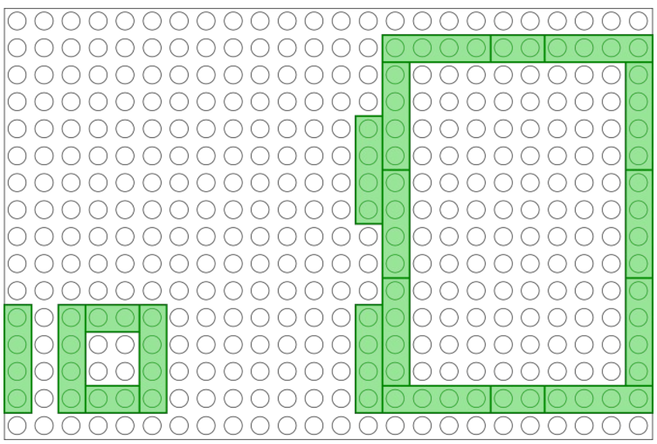


Below is a description of how to construct each layer to yield very good overall results.

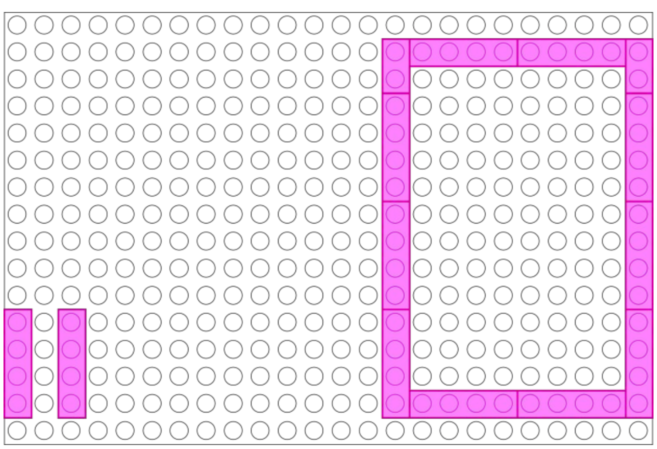
Layer 1 (Key: yellow = bricks; pale pink = 2 × 4 flat tiles)



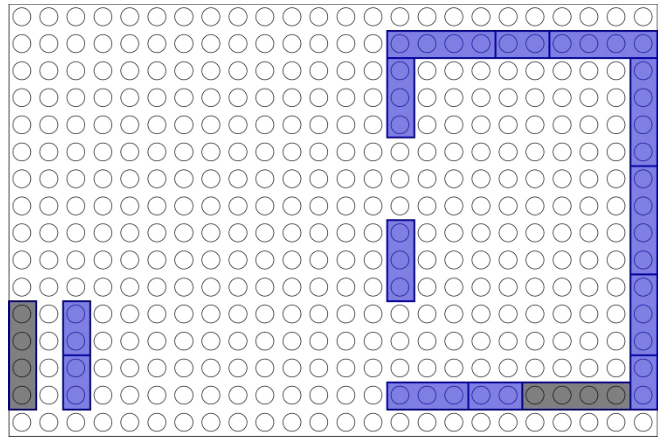
Layer 2 (Key: green = bricks)



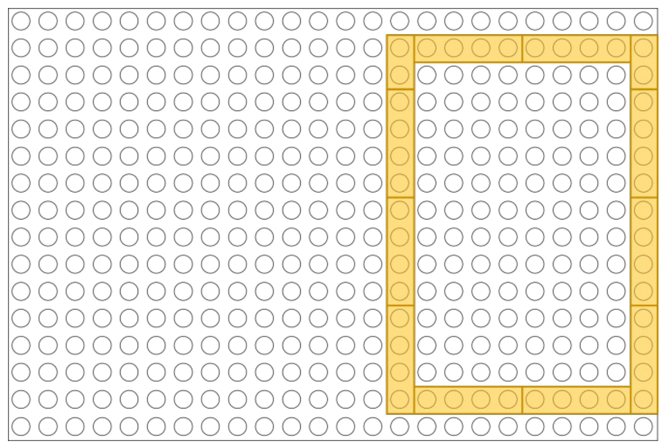
Layer 3 (Key: pink = bricks)



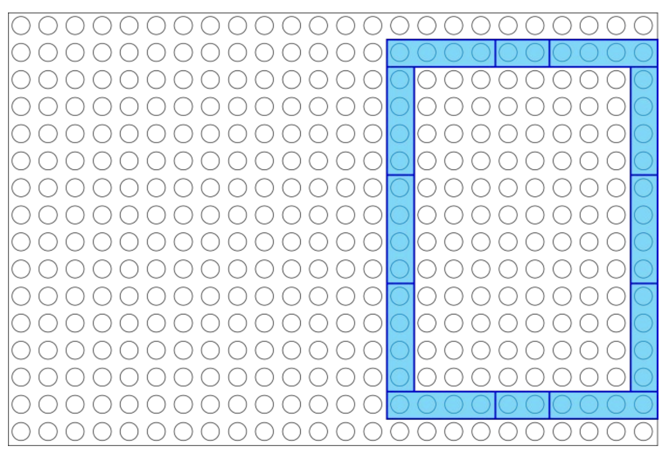
Layer 4 (Key: blue = bricks; black = LED brick in two possible positions)



Layer 5 (Key: orange = bricks)



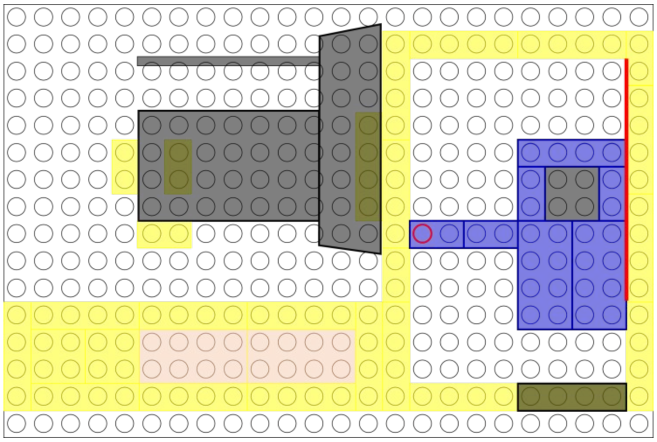
Layer 6 (Key: blue = bricks)



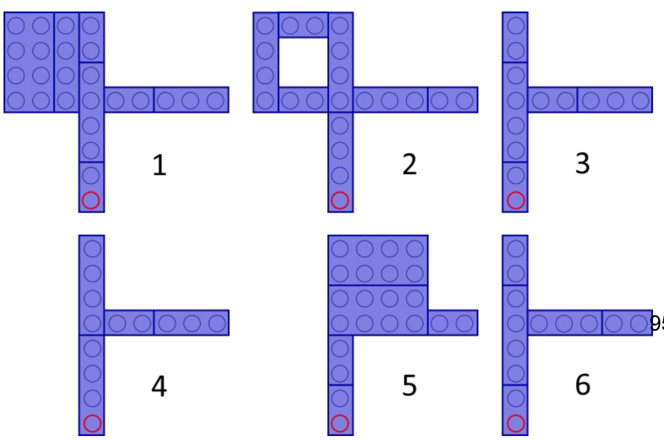
Fluorescence imaging: Set-up #1

Key: yellow-bricks (above); black = webcam, LED and sample (above); blue = insert.

Solid straight red line = white card.



Insert by layers (numbered)

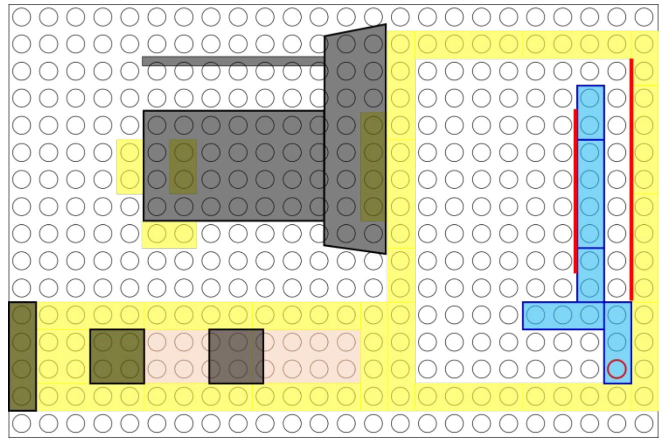


Red circle to indicate orientation in set-up.

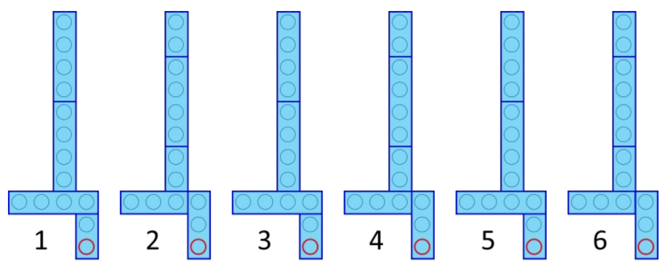
Absorption spectrometer: Set-up #2

Key: yellow-bricks (above); black = webcam, LED and sample (above); blue = insert.

Solid straight red line = white card.



Insert by layers (numbered)



Red circle to indicate orientation in set-up.