Bouguer-Lambert-Beer law

(exp. id 2020101012-1-vl)

An experiment proposed by:
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Overview

This experiment is devoted to the study of the attenuation of the illuminance produced by a source when its light passes through a material medium.
The measurement of the illuminance can be done using the ambient light sensor present in several smartphones.
For the experiment we measure the illuminance as a function of the light path length for a given medium.
Thanks to the sensitivity of the sensor installed on smartphones, it is possible to register illuminance variation of the order of 1 lux.
The plot of the collected data can be easily analyzed in order to deduce the Bouguer-Lambert-Beer law and to estimate the light absorption coefficient of the used material.

Materials

- A smartphone with an ambient light sensor
- A kitchen lampholder with a led bulb
- A cylindrical cardboard tube with a diameter of 4 cm and a height of 25 cm
- 20-30 squares of transparent material (with an area of about 40 cm^2) obtained from 0,2 mm thin PVC stationery A4 binding covers
- A measuring tape

Making the measurements

This experiment requires a smartphone equipped with an ambient light sensor.

You can find the ambient light sensor among the sensors listed by the app PHYPHOX.

Clicking on the small pulsing triangle on the top right of the display (start button) the sensor starts registering the illuminance.

You can either visualize the numerical values or an illuminance vs. time plot.
For the experiment:

1. place the smartphone above an horizontal plane at a distance of 1 m from the led bulb suspended along the vertical direction which intersects the ambient light sensor
2. place the cylindrical cardboard tube on the smartphone screen with its longitudinal axis along the vertical direction
3. after 10 seconds of data acquisition put a first PVC transparent square on the top side of the tube and wait for another 10 seconds
4. repeat the above step for any added transparent square

The app PHYPHOX allows to collect the acquired data into an Excel sheet in order to:

- evaluate the average value of the illuminance for any light path length
- evaluate the standard deviation associated to any average value of the illuminance
- compare the above standard deviation with the sensitivity of the ambient light sensor of the used smartphone
- plot the illuminance as a function of the light path length

General remarks

Always try to estimate the uncertainties of each measurement properly. Can you spot any source of systematic error? Can you estimate its size? Before starting any series of measurements, make few tests to train your ability to perform operations seamlessly. Note the measurements neatly and in a complete way (indicating values, uncertainties and units). Use tables and graphs appropriately.

Making and reading the graph

Make a linear plot of the *Illuminance* vs the *light path length*. Pay attention to the scale on the axes. In a well-done graph, the experimental points should be well spaced on both axes. Are the plot points aligned each other or not? What does it mean?

Let E_n be the illuminance measured when the absorbing material is composed of n squares. What's about the linear plot E_{n+1}/E_n vs. n ?

Using the same data make a log-linear plot of the *Illuminance* vs the *light path length*. Draw the best fit and then read on the graph its intercept with the vertical axis and then estimate the slope. What do these values mean?

For the instructor

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1. A simple way to treat the data is to log it on a google spreadsheet. At university level, it would be appropriate to save data in text files, and retrieve the files via python scripts for plotting and fitting.
2. The best fit of a graph can be drawn in many ways, more or less complicated. It is up to the instructor to choose the method appropriate to the class.
3. The linear plot E_{n+1}/E_n vs. n shows that for any added transparent square the illuminance diminishes of a constant factor and this is a sign of an exponential attenuation (i.e. the Bouguer-Lambert-Beer law)
4. The slope of the line in the log-linear plot can be used to determine the light absorption coefficient of the material medium while the vertical intercept gives us the illuminance registered by the sensor in absence of the material medium.
5. In this experiment the led bulb does not emit monochromatic light, consequently the estimate of the light absorption coefficient (which depends on the wave length of light) has to be regarded as an average value.
6. This experiment has been tested with success by a team of high school teachers in a training course at Sapienza Università di Roma

Objectives

1. Primary objective: Enjoyment and practice in empirical experiments.
2. Primary objective: Development of scientific investigating skills
3. Primary objective: Obtaining data that can be plotted and fitted, without requirement of much analysis.
4. Suitable for: high school.
5. Duration: no more than 1 hours of data acquisition, + 1 hour of data plotting, + writing short report.

Further Info Online

Please leave feedback, suggestions, comments, and report on your use of this resource, on the channel that corresponds to this experiment on the Slack workspace "smartphysicslab.slack.com".
Instructors should register on the platform using the form on `smartphysicslab.org` to obtain login invitation to the Slack workspace, and/or to request being added to the mailing list of smartphysicslab. .....