Light absorption in media

(exp. id 2020101012-1-v2)

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 light passes through some medium.
The measurement of the illuminance can be done, e.g., by using the ambient light sensor present in many 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 analysed 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 about 4 cm and a height of 20-30 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 visualise the numerical values or an illuminance vs. time plot.

For the experiment:

1. place the smartphone above an horizontal plane at a distance of the order 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, to select light directly coming from the bulb;
3. after about 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.

PHYPHOX allows us to collect the acquired data into a table that can be exported in various forms, 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, measured in units of the number of absorbers. 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 its intercept with the vertical axis on the graph; 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
4. Light attenuation is partly caused by light absorption by the traversed medium, and partly due to Fresnel reflection of the light beam on the surfaces of the absorbers layers. In certain cases, it is possible to give rise to interference phenomena that may even cancel the transmitted light.
5. The experiment can serve to study the Beer-Lambert law, substituting the plastic absorbers with a transparent liquid with different concentrations of a dye, relating the light transmission to the dye concentration.
6. The slope of the line in the log-linear plot can be used to determine the light absorption coefficient, while the intercept gives us the illuminance registered by the sensor in absence of the absorbers.
7. In this experiment the led bulb does not emit monochromatic light, consequently the estimate of the light absorption coefficient (which depends on the wavelength λ of the light) has to be regarded as an average value. The same experiment can be done using lasers of different colours to show how the transmission coefficient depends on λ.
8. The experiment can be done in order to introduce exponential laws, as well as the solutions to separable differential equations.
9. 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.

Revision history

- v2 [G.Cristofolini]: removed explicit references to the Beer-Lambert law (but in the proposed variation of the experiment, in the teacher's section), to make the experiment more generic and taking into account other phenomena. The effects of the Fresnel reflections and possible interference is discussed.

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.