82. Polarization of Light - Malus' Law

I. Introduction

1. Polarization of light

Read the first chapter, section 1 - 4, of the manual "19 - Polarization". This will give you a solid background required for this experiment.

2. Malus' Law

Consider a beam of linearly polarized light incident upon a linear polarizer. The amplitude of the electric field before the polarizer is E_0 and its intensity is $I_0 \sim E_0^2$. Let Θ be the angle between the axis of the polarizer and the polarization of the incident light. The electric field that passes through the polarizer is the component in the direction of the axis, $E = E_0 \cos\Theta$. Therefore, the intensity of the light passing the polarizer is

$$I = I_0 \cos^2\Theta. \tag{1}$$

This is the so-called Malus' Law (see Fig. 1), named after the French physicist Étienne-Louis Malus, who discovered optical polarization in 1808.

3. Requirements

In order to be able to perform this experiment, you need the following:

- Smartphone with the Physics Toolbox Sensor Suite app (see next section) **Note**: the app does not work on iPhones, as it does not allow you to access the light intensity sensor. You can use e.g. the free App "lux light meter" for iOS devices.
- Source of polarized light, e.g. a flat-screen monitor
- Polarizing lens, e.g. 3D cinema goggles / polarized sunglasses
- Computer for data analysis & report

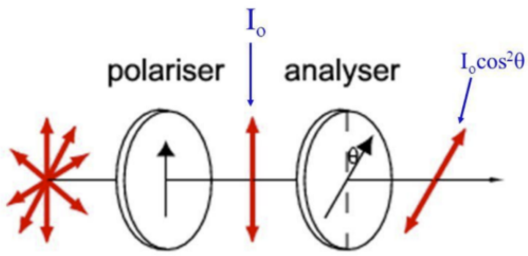

Figure 1: Illustration of the polarization states after a polarizer and after the analyzer.

Hint: for best results, perform the experiment in a relatively dark room, where you can make sure that the measured light source is the main source of light intensity (i.e. block the sunlight and turn off other lights in the room).

II. Tasks

Perform the experiment in order to verify the validity of Malus' Law (Equation 1). You will measure the amount of light passing through a polarizing lens versus the angle between the source and the lens and graphically demonstrate the equation.

III. Carrying out the experiment

1. Qualitative observation

Look through the polarizing lens at the source of polarized light. Slowly rotate the lens and observe the amount of light you can see. Perform the experiment for each side of the lens facing towards you. Describe what you observe.

2. Configuring the Software

Download the *Physics Toolbox Sensor Suite* app and install it on the smartphone (see Fig. 2).

Access the app and enter the Multi Record option. Select the Light Meter sensor and the Inclinometer sensor (see Fig. 3).

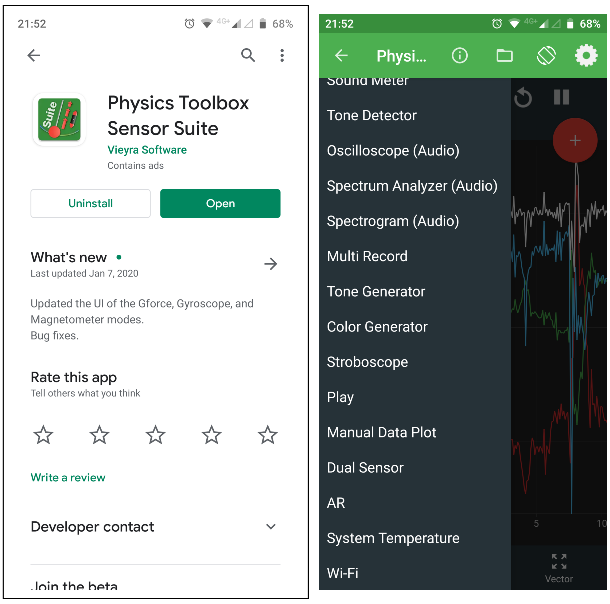

Figure 2: Download the app on the smartphone, then go under Multi Record in order to simultaneously acquire data from multiple sensors.

3. Setting up the measurement

Attach the polarizing lens to the light sensor of the smartphone (e.g. using an elastic band). After solving Point 1., you should know looking through which side of the lens displays the effect in the most obvious way. This is the side that should face the light sensor. (The smartphone light sensor is usually situated on the front of the device.) Once launched, the measurement will track and record simultaneously all sensors (in Fig. 3, two) selected.

4. Performing the measurements

Start the recording of the data, then place the smartphone with the attached lens on the source of polarized light. Then slowly rotate the smartphone for at least one full turn (180°).

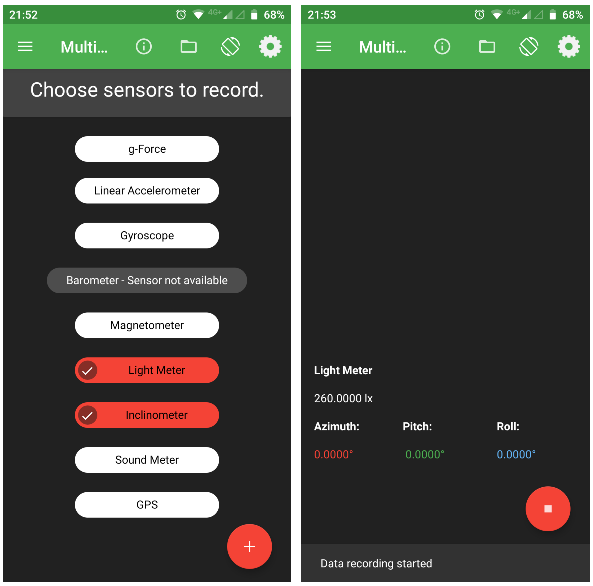

Figure 3: Select both Inclinometer sensor (to measure the angle of the smartphone around 3 axes) and the Light sensor (to measure light intensity).

Tips:

- Make sure the rotation speed is small enough, in order to get enough data points. The rate of acquisition of data points can be toggled between "Fastest" ($\sim 200Hz$) and "Slowest" ($\sim 1Hz$), under Options.
- Though it should not influence the data acquisition significantly, try not to move the smartphone too much across the screen during the measurement. You should also have a static image on the screen while doing this.

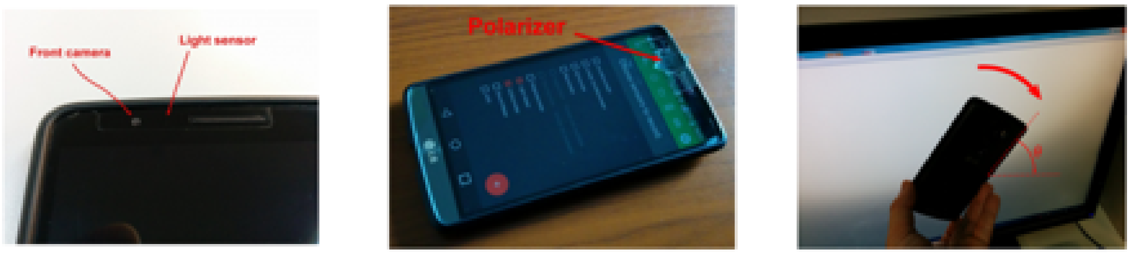

Figure 4: Example of mounting of the polarizing lens on the light sensor and performing the experiment.

5. Analyzing the data

Upon finishing the measurement, stop the recording of the data. Save the values in a file which you then open in a data analysis program (e.g. Matlab, Excel etc.).

Proving Malus' Law means plotting the intensity measured vs. the inclination angle of the smartphone. You must verify the accuracy of the measurement by plotting this acquired data together with the theoretical curve predicted by the equation (Equation 1). Explain what you observe.

In addition, in order to verify the accuracy of your measurement, plot the natural logarithm of the normalized intensity vs. the natural logarithm of the cosine of the angle. This should yield a curve that matches a linear fit reasonably well. You can quantitatively assess this by the R^2 factor of the linear fit. Explain what you observe. (*Note: For this part, you might have to select only the data points for angles below* 90°.)

IV. Report

Since the experiment itself is not considered particularly difficult, the writing of the report is a major part of the laboratory class, and a quality report is key to obtaining the passing grade.

1. You typically have 1 week to submit the report (by e-mail). Should you need more time, please let us know before the deadline so we do not decline your 'testat'.

2. The report must consist of a single .pdf file, which includes all data, figures and text as a coherent document. Please do not simply attach several workbooks, a text document and several figures into an archive.

3. Make sure you include:

   (a) all tables - containing all data, formatted and legible, with quantity names and units as table headers, numeric values trimmed to significant digits. Should you need to discard data, please mark it appropriately and explain why in the text.

   (b) all figures (plots) - formatted, with axis labels (including units), relevant axis range, and error bars (where applicable)

   (c) *brief* explanation of the theory

   (d) description of the setup - with detailed explanations of the mounting and measurement techniques. Attaching pictures is encouraged.

   (e) answers to all questions - (see Section V.), either separate or within the main text. These questions should be attempted before the experiment is completed.

   (f) data analysis - with explanation for any data manipulation you perform (e.g. curve fitting) and comments on the results, conclusion (e.g. how do you know the experiment was successful), potential error sources (try to approximate error ranges, where applicable). Please make sure you discuss the results: if they look good, or if it is the case, why not, e.g. do not simply say that the plot doesn't look as expected and submit it anyway. You risk being asked for a resubmission.

Note: this is why consulting with the assistants during the class is essential.

(g) brief explanations of observations or expectations, where specifically asked in Section III.

(h) any other comments and discussion, e.g. how you would improve the experiment setup (within the given constraints)

4. During the class, you are encouraged to ask questions in order to clarify any issues that might occur, as well as to check with the assistants whether your data, methods and results are reasonable. Since they do not see directly the experiment being performed, the more feedback you give, the easier it is for them to guide you in the right direction.

V. Questions for students while preparing for the experiment

1. Give examples of longitudinally and transversally polarized waves!
2. How is natural light polarized?
3. How can light be polarized in this experiment?
4. At which relative (between lens and source) angle do you obtain minimum light transmission? What about maximum?
5. What do you physically achieve, within the experiment, by rotating the smartphone on the screen?
6. How do you expect the first plot (intensity vs. angle) to look like? What is the period of this curve?
7. In the second plot (ln(I) vs. ln(cos(theta)), what does the slope of the linear fit represent? What is the ideal value for this quantity?