Luxembourgish Physics Olympiad

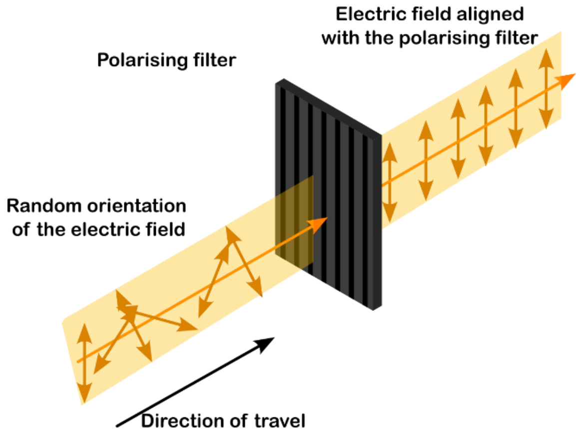
Final

Introduction

Light is an electro-magnetic wave that travels through space. It consists of electric and magnetic fields that oscillate perpendicular to the direction of travel. For simplicity's sake, we will only consider the electric field.

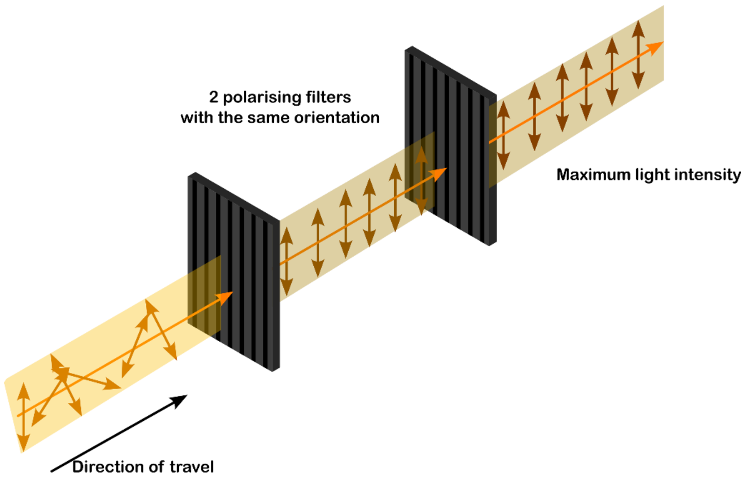
F light of a normal light source (incandescent light bulb, sun...) the orientation of the electric field oscillation is completely random. This is called unpolarised light.

However, some materials only allow light to pass through if the electric field oscillates along a specific direction. Such a material is called a polarising filter which produces linearly polarised light, where the electric field only oscillates in a specific direction.

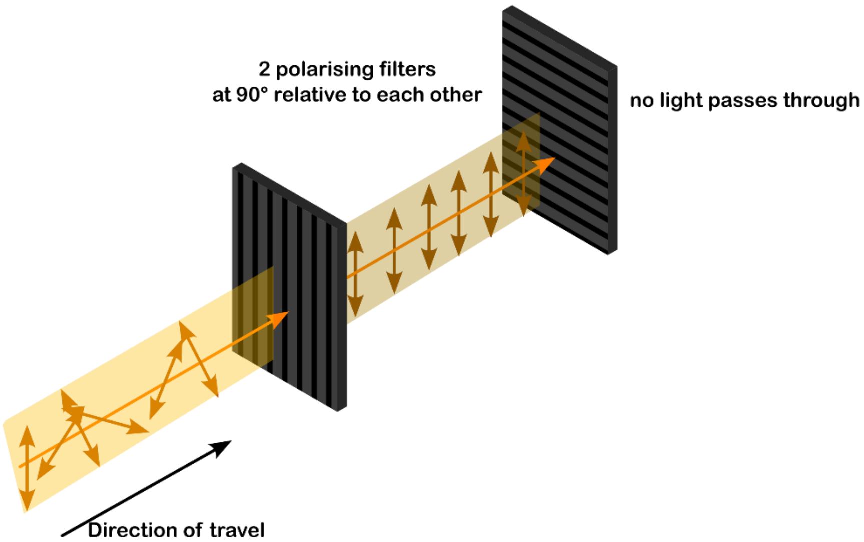


When two polarising filters are placed in series, the polarised light that went through first filter will fall on the second filter. In this case, there are three possibilities.:

1. The two polarising filters are perfectly aligned. Then the second filter has no effect on the light, and it can pass through unimpeded.



2. The two polarising filters are rotated by 90° with respect to one another. Then the light from the first filter cannot pass through the second filter and is absorbed entirely.



3. In any intermediary position, some light will make it through both filters, but the light intensity will be reduced depending on the alignment of the filters.

In this experimental session, you will in a first step examine how the relative angle between the filters influences the light intensity.

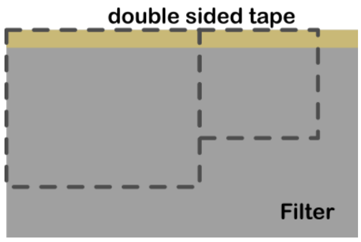
In the second and third part, you will study the effect of sucrose on the plane of polarisation. In fact, sucrose is a chiral molecule that interacts with polarised light and changes the axis of polarisation. This phenomenon may depend on the wavelength of the light and the concentration of the sucrose solution.

Materials

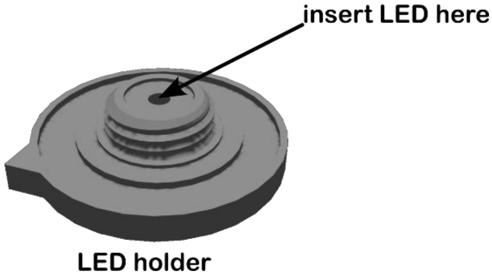
- cardboard
- 3D printed box
- 3D printed LED holder
- 3D printed nut
- Printed angle scale
- concentrated sucrose solution
- measuring cylinder
- Erlenmeyer flask
- 250 ml beaker
- graphing paper
- LED‘s of different colours
- Duct tape
- IPad with Phyphox installed
- polarising filter
- scissors
- Lithium coin cells
- Double sided tape
- cutter

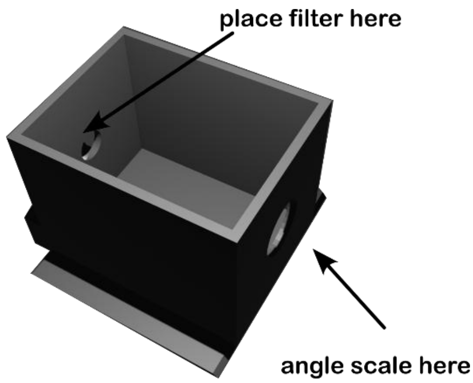
Preparations

1. Cut out the angle scale and glue it on the side of the 3D printed box (side with the bigger opening) using strips of double-sided tape.
2. Cut out the hole in the middle using the cutter.
3. Cut out a thin strip of double-sided tape and glue it along the side of the polarising filter. Cut out two squares with dimensions 2cmx2cm and 1,5cmx1,5cm. Glue the larger square on the inside of the box over the small opening. The double-sided tape should be above the hole. Keep the smaller one for later.



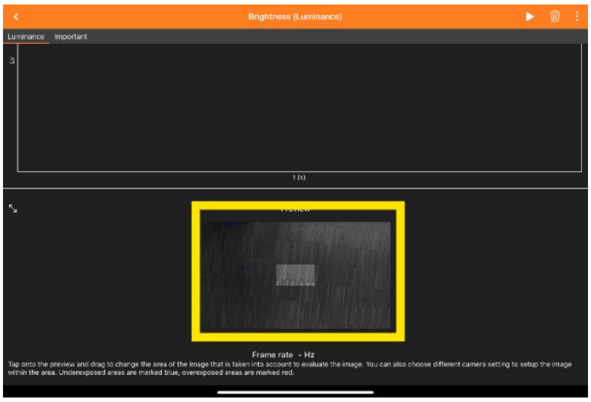
4. Insert the legs of the blue LED into the LED holder.

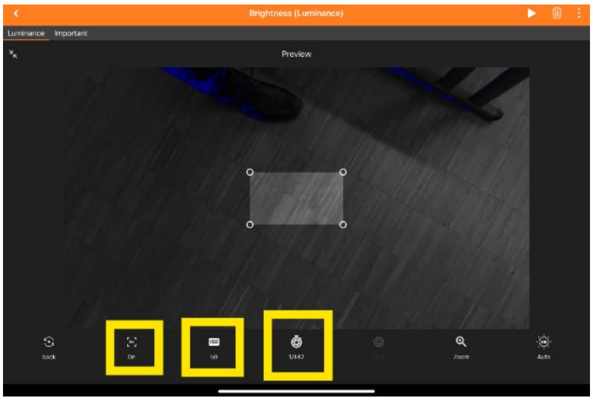


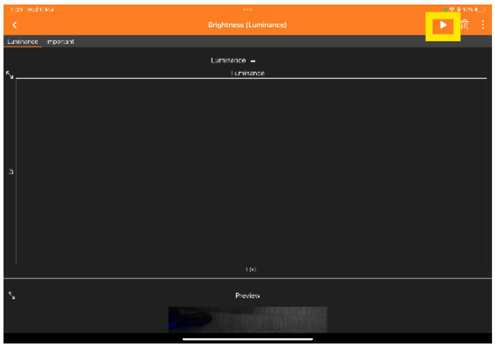


5. Place two coin cells in series and insert them between the LED legs so that the LED lights up. Friction should keep the coin cells in place, if not add a piece of duct tape. The long leg of the LED corresponds to the positive terminal.
6. Place the LED holder in the larger opening of the 3D printed box and secure it with the nut. Tighten the nut so that you can still turn the dial. If the holder does not fit properly, ask for help.
7. Set the dial to the top position (0°) and glue the small square of the polarizer on top of the LED with the double-sided tape on the top. Verify, by looking through the opening at the LED. The LED should brightest at 0° on top and dimmest when the dial is at 90°. If that is not the case, adjust the polariser position.
8. Cut out a piece of cardboard that fits the top of the box and glue it along one side using duct tape to the box like a hinge. This allows you to close the box to prevent reflections from ambient light.
9. Use duct tape to cover the sides of the beaker leaving two diametrically opposed strips with a width of five millimetres free so a light can shine through the centre of the beaker.
10. Put the iPad on the inclined holder on the box so that the camera points through the small opening. Secure the iPad to the box in that position using two thin strips of double-sided tape.

11. We will use the iPad with the Phyphox App to measure the light intensity of the LED. Open the app and go into brightness luminance mode. By tapping on the bottom image, you can adjust the settings of the camera. Select an area that only encompasses the LED.
12. For a correct measurement ensure there are no over exposed areas on the image which are shown in red. Black areas are under exposed. Turn automatic exposure off as this will give you inconsistent results. You can manually increase the ISO number or the exposure time to increase the sensitivity.







13. By tapping on the live image again it will minimise. Then scroll to the graph with the measurement. Tap on play to start the measurement. The brightness/luminance value is given in arbitrary units and depends on the camera settings. We assume it to be a linear function ($y = a \cdot x + b$) of light intensity for a given camera setting if there is no saturation of the camera sensor.

Experiment 1

Verify Malus' law which claims that the transmitted light intensity should be:

$$I = I_0 \cos^2(\alpha)$$

Take measurements over from 0° to 90° with 5° steps. And plot a graph of the intensity as a function of the angle using graphing paper.

Then linearize the graph by calculating the $\cos^2 \alpha$ and drawing a new graph.

Experiment 2

Sucrose is an achiral molecule that acts on polarised light by rotating the axis of polarisation.

1. Align the polarisers at 90° to each other so that the light intensity is minimal without the solution. To determine the rotation by a sucrose solution, we will look at this minimum of intensity when we interpose the sucrose solution. In this case a linear measurement is less important, so you may oversaturate the sensor to get a more accurate measurement of the minimum intensity angle.
2. Pour the sucrose solution into the beaker and put it in the light path so that the light hits the camera sensor.
3. Adjust the camera settings if necessary.
4. Determine by what angle the minimum has shifted for this color of LED.
5. Repeat the experiment with the different colors of LED.
6. What trend to you observe?
7. Does this remind you of a similar effect where light is influenced?

Experiment 3

1. Choose a LED color from the last experiment and install it once more.
2. Using the provided sucrose solution determine the effect of concentration on the rotation angle. To obtain different solutions, you must dilute the concentrated solution. This process is irreversible, so check your results carefully before proceeding with a dilution.
3. Proceed to measure four different concentrations using the same method as in experiment 2.
4. Show that the rotation angle α is proportional to the concentration c.
5. The rotation angle α is also proportional to the light's path length ℓ in the solution. From there determine the specific rotation k of the sucrose solution.

   $$k = \frac{\alpha}{c\ell}$$

   Use ° , $\frac{g}{ml}$ and dm for the respective units
6. Estimate the measurement error.