Experiment #: 10

Experiment Title: Malus' law

Objectives:

1. To measure the variation of the transmission of radio waves through 2 polarizers as the orientation angle between them is changed

This is a quantitative continuation of the “Polarized or Unpolarized” activity and should be done in this order.

Theory:

Originally an empirical law, nowadays Malus' law is seen as a key experiment to demonstrate the transverse nature of electromagnetic waves, as well as the intrinsic connection between optics and electromagnetism. In this work, a simple and inexpensive setup is proposed to quantitatively verify the nature of polarized light. A flat computer screen serves as a source of linear polarized light and a smartphone (possessing ambient light and orientation sensors) is used, thanks to its builtin sensors, to experiment with polarized light and verify the Malus’ law.

Smartphone-based experiments and optics

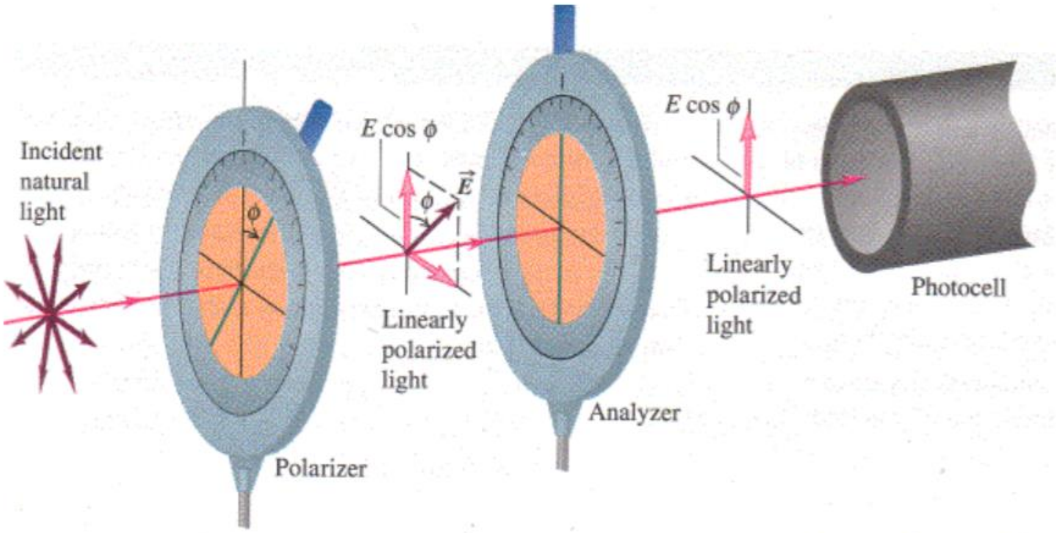
In the last years, a great deal of smartphone-based experiments have been proposed in physics. Remarkably, experiments focusing on light and optics, and specially those using the ambient light sensor1-2, have received little attention compared to those focusing on mechanics, oscillations or magnetism. Two exceptions are worth mentioning. In Ref.1 , the authors proposed a simple verification of the inverse square law using the light sensor of a smartphone or a tablet. In a different approach2 , the ambient light sensor has been proposed to indirectly measure distances and to analyze coupled springs undergoing oscillatory motions. Here, we focus on an experiment using the ambient light sensor which involves the polarization of light3-9 and, in particular, the Malus’ law. Smartphones also gives us the ability of measuring simultaneously with various sensors. This is also a great advantage since it allows a great variety of experiments to be performed, even outdoors, avoiding the dependence on fragile or unavailable instruments. In previous works, the simultaneous use of two sensors like the gyroscope and the accelerometer was proposed to relate angular velocity, energy, centripetal and tangential acceleration10-12. In another experiment, the pressure sensor and the GPS were used in synchrony to find the relationship between atmospheric pressure and altitude13 . In this work, we propose an experiment in which we take advantage of the capabilities of a smartphone to verify the Malus' law. The intensity of polarized light from a computer monitor is measured by means of the ambient light sensor with a tiny polarizer attached to it while the angle between the polarization and the polarizer is measured by means of the orientation sensor. The simultaneous use of these two sensors allows us to simplify the experimental setup and complete a set of measures in just a few minutes. The experimental results of the light intensity as a function of the angle shows an excellent agreement with Malus' law.

Polarized light

Light, as any other electromagnetic wave, nearly always propagates as a transverse wave, with both electric and magnetic fields oscillating perpendicularly to the direction of propagation (see a standard general physics textbook). The direction of the electric field is called the polarization of the wave. In a linearly polarized plane wave the electric field remains in the same direction. This pure state of polarization is called linear polarization. Natural light, (e.g., light radiated by an incandescent object) as a random mixture of waves with different polarizations, is unpolarized light, or more precisely, random polarized light. According to conservation of energy applied to electromagnetic fields (Poynting's theorem), the energy flow (intensity or illuminance, I) associated to an electromagnetic wave (light) is proportional to the square of the amplitude of the electric field. When light interacts with matter its behavior is modified, mainly its intensity and its velocity. Moreover, some materials are able to modify light differently in each spatial direction. This is the case for instance of linear polarizers that can convert unpolarized light into linear polarized light. An ideal polarizer fully attenuates light polarized in one direction, and fully transmits light with the orthogonal polarization. Consider a beam of linear polarized light incident over a polarizer. 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

$I = I_0 \cos^2 \theta$ (1)

where I_0 , is the intensity of the light before the polarizer. Equation 1 is the so called Malus' law, named after the French physicist Étienne-Louis Malus, who discovered optical polarization in 1808.



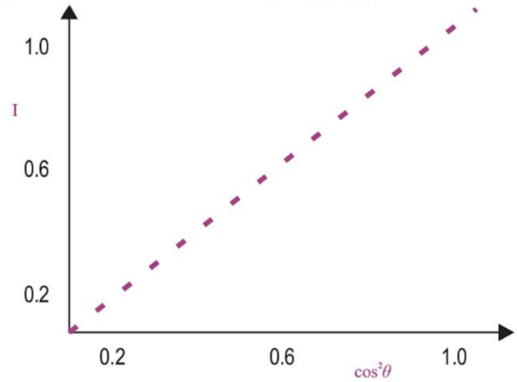


Fig. Photo detector current as a function of $\cos^2\theta$

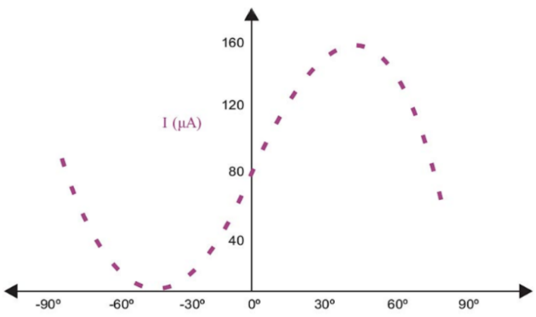


Fig. Photo detector current as a function of angular position of polarization plane of the analyzer

List of Equipment:

Apparatus

1) VSRT System (See Appendix I)

2) Single CFL set 2 feet from detectors next to each other (~2.5 inches center to center)

3) Polarizers (~2mm wide / ~2mm spacing) made from metallic tape (Cu or Al) and Polarizer Holder marked at 10° Increments (or mounted to a protractor)

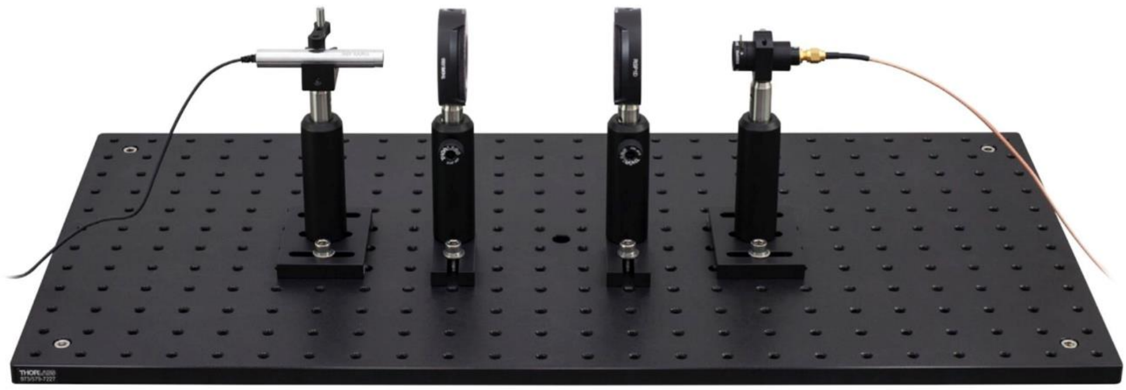
Circuit Diagram:

Procedure:

Part I - Malus' law

Preliminary experiment: place two polarizers in front of the laser and adjust them so that their transmission axes are perpendicular to each other. Now hold a third polarizer (film without holder) between the two crossed polarizers and rotate it. What do you observe and why?

Demonstrate the validity of Malus' Law: Place a polarizer in front of the laser. Orient it so that the brightness of the transmitted light is maximized (estimation by the naked eye suffices).
Now place a second polarizer in the beam path and place the photodetector behind it, as shown in Figure below. Rotate the second polarizer at an increment size of your choice and record the voltage values on the photodetector. Estimate measurement uncertainties, plot your results and retrieve the Malus's law empirically.



Measure the state of polarization of the laser: Position a polarizer in front of the laser. The photodetector is again positioned behind the polarizer, as shown in the figure below.

Now rotate the polarizer at an increment size of your choice and measure the photodetector output. The polarization properties of the CPS532-C2 laser modules vary from model to model. Record your measurement and note your findings (in general, the polarization is not linear, but elliptical).
The specific state of polarization (i.e. linear or elliptical) does not affect the other tests in any way – if a linear polarization is required, then we place a polarizer in front of the laser

Data Collection:

Data Table:

Angle [°]	* Power [K]	% Transmission	Theoretical Transmission [%])	% Difference
0				
10				
20				
30				
40				
50				
60				
70				
80				
90				
			Average % Diff. =	

*** - See <u>Basic VSRT Operation</u> for discussion of Power [K]**

Calculation:

1) Calculate the % Transmission by dividing the Power at a certain angle by the Power at 0°. { Note: The results should be less than 100% }

2) Compute the theoretical transmission by taking the cosine of the angle, then squaring it and multiplying by 100 for a percentage;

i.e. – Trans(theo) = $\cos^2 \theta$ *100%

3) Calculate the % Difference = (% Transmission – Theoretical Transmission)

Theoretical Transmission

4) Average the % Difference and place result in the shaded box on lower right.

Graphing:

1) Setup the graph for the % Transmission (0% to 100%) vs. Angle (0° to 90°) adjusting the scale of the axes to maximize the size of the graph.

2) Graph the measured transmission (2nd column) vs. angle and label it.

3) Graph the theoretical transmission (3rd column) vs. angle and label it.

Result:

Sample Results:

Malus' Law using 12GHz radio waves

Right Polarizer - Horizontal

I(max) = 160

Angle [°]	Signal	Fit=I(max)*cos²θ
0	162	160
10	159	155
20	126	141
30	109	120
40	86	94
50	60	66
60	55	40
70	31	19
80	18	5
90	7	0