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Realization of Polarization and Malus's Law Using The Smartphones

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ABSTRACT

This work provides an approach for simplifying and teaching of the confusing topic of Polarisation of light and relating Malus's Law. Teaching Polarisation and the Malus's Law are modestly achieved by means of smartphones with a convenient light meter application. The apparatus is designed so that the polarizer, the analyser, the laser light source and the smartphone are precisely aligned on a rail. During the performance, the angle of the analyser is basically varied with respect to the polariser and the transmitted light intensity is measured by the light meter application. The results clearly show that the transmitted light intensity is directly proportional to the squared polarization angle. The approach surely provides accessibility for physics teachers and would help students to learn and internalize Polarisation and relating Malus's Law in a better manner.

Keywords: Malus's Law; Physics Education; Polarization; Smartphones

INTRODUCTION

Physics naturally experience pronounced difficulties in educational and instructional issues because of being comprised of both heavy mathematical expressions and very complicated and interrelated concepts (Retnawati, Arlin, Wulandari, & Pradani, 2018). Many researchers have repeatedly expressed that most students find physics as the most difficult subject of all, charging physics educators some heavy duties (Caleon, Tan, & Cho, 2018; Zhang, Wang, Liu, & Jiang, 2018; Caldarelli, Wolf, & Moreno, 2018). Nevertheless, physics educators have recently achieved some considerable exceptional progress over the globe, due to great developments in mobile technologies. Thanks to the technologies that have been advancing rapidly, many measurement applications have been developed depending on the invaluable sensors of the smartphones. The smartphones are recently being intensively used for educational purposes in almost all areas, but especially in physics and physics education (Erol, & Çolak, 2018; Çoban, & Erol, 2019; Dilek, & Erol, 2018a; Dilek, & Erol, 2018b; Salinas, Monterio, Marti, & Monsoriu, 2019; Staacks, Hütz, Heinke, & Stampfer, 2019; Pili, & Violanda, 2019) The smartphones are nowadays fabricated with extremely sophisticated sensors that are embedded into and can be used to measure many crucial physical quantities such as acceleration, position, angle, magnetic field, loudness, light intensity etc. by means of developed many priceless applications. In recent studies, it has been intensively reported that the smartphones can be used as an alternative to expensive and inaccessible instruments in physics education (Vogt, & Kuhn, 2012; Chevrier, Madani, Ledenmat, & Bsiesy, 2013; Kuhn, & Vogt, 2013; Egri, & Szabo, 2015; Mazzella, & Testa, 2016; Kapucu, 2017; Abidin & Tho, 2018; Staacks Hütz, Heinke, & Stampfer, 2018; Pili, 2018; Fakhruddin, 2008; Gladden, 1950; Gottlieb, 1980; Mešić, Hajder, Neumann & Erceg, 2016; Monteiro, Cabeza & Martí, 2015; Monteiro, Vogt, Stari, Cabeza, & Martí 2016).

Therefore, it would obviously be very useful to employ the smartphones in physics classes, as it is very important for students to be able to draw up a link between the complicated equations and everyday life. In certain cases, though, the sensors are found inade-

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quate in terms of measurement accuracy and some additional applications, fully incorporate the features of tablets with intuitive interfaces, built-in sensors and multi-touch screens are additionally designed (Wang, Wu, Chien, Hwang, & Hsu, 2015).

Noticeably, experiments were focusing on light and optics, especially those using the ambient light sensors, have however received diminutive attention compared to those focusing on mechanics, electricity or magnetism (Monteiro Stari, Cabeza, & Marti, 2017). Recently, Monteiro and others have measured the light intensity by changing the angles of the polarizer placed on the top of the light sensor of the smartphone by using the light meter, taking advantage of the polarized light from the computer screen (Monteiro, Stari, Cabeza, & Marti, 2017). In a study by Benenson, he worked on the polarization of the diode laser (Benenson, 2000). Sans, Manjón, Pereira, Gomez-Tejedor, & Monsorju were able to calculate two damping times and periods of the damped oscillation, using the light sensor of the phone from the light intensity curves (Sans, Manjón, Pereira, Gomez-Tejedor, & Monsorju, 2013).

Polarisation of the light or electromagnetic waves is a topic in physics education, facing certain difficulties to understand and to properly teach. Malus's Law, on the other hand, directly expresses the polarisation and the relation between the relative intensity and the angle of the polariser (Monteiro Stari, Cabeza, & Marti, 2017). The Malus's Law, in other words, describes the polarization of light and also proves the correctness of the square law. It is generally found difficult to analyse and internalize the phenomenon of polarization, which is in fact an electromagnetic wave with electric and magnetic fields directed on a single direction perpendicular to each other. In this study, an easy-to-use teaching tool is designed for the demonstration of the polarization of light and the Malus's Law. The approach offered here is important in terms of ease of the operation and uncomplicated applicability for physics educators and students.

METHOD

The designed apparatus is comprised of a He-Ne gas laser source, a vertical polarizer, an analyser with adjustable anglemeter and a smartphone with a Light Meter application loaded. The He-Ne laser source, specifically employed, emits red light with a power of 1mW and a wave length of 632.8nm. The photography of the apparatus is shown in the Figure 1.

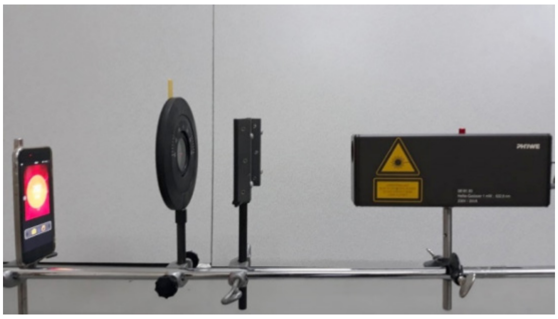

Figure 1. The photography of the apparatus.

In order to achieve preeminent results, the vertically oriented polarizer, the analyser, the laser light source and the smart phone window is aligned horizontally with high precision, as shown in the Figure 1. The actual measurements are performed as follows; the laser light source initially emits unpolarised red light immediately reaching to the polarizer and polarised vertically and transmitted. The transmitted and polarised red light surely reaches to the analyser and by simply varying the orientation angle of the analyser, with respect to the polarizer; one can easily measure the intensity of the transmitted light, which is I, by means of the light meter app of the smart phone.

The Light Meter application specifically employed here is developed by Nipakul Buttua and can be accessed by anyone at, https://itunes.apple.com/us/app/lux-light-meter-free/id1171685960?mt=8 from the AppStore. The application is quite easy to use and typical screen shut of the application is given in the figure 2. This application is rather advantageous due to giving actual mean values of the overall light reaching to the sensor. The design is quite beneficial in the sense that smartphones are widely used by the students over the globe and the smartphones are embedded with very powerful applications that make them exceptionally advantages with respect to the classical light detectors.

RESULTS AND DISCUSSION

Light, in fact, is made up of electromagnetic waves and comprised of any orientation of the electric and magnetic field vectors, that means no polarisation normally occurs, unless otherwise is stated.

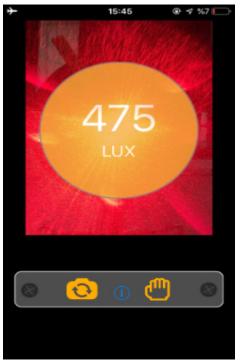

Figure 2. The photography of light meter application employed in the study

The energy flow rate of an electromagnetic wave is basically expressed by the Poynting vector, $\vec{S}$. For the electromagnetic waves, the electric and magnetic field vectors are always perpendicular to each other and sinusoidal at any point, therefore the Poynting vector continuously changes over time. Since the frequencies of typical electromagnetic waves are very high, the Poynting vector changes over time very rapidly, therefore one needs to deal with the averages instead of instantaneous values. The average value of $\vec{S}$, at any point, is called the Intensity; I, which expresses the energy flow per unit time and per unit cross sectional area. The energy flow rate of an electromagnetic wave, Poynting vector, $\vec{S}$, can be formulated as,

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B} \qquad (1)$$

where μ_0 is the magnetic permittivity of free space, $\vec{E}$ denotes the electric field vector and $\vec{B}$ denotes the magnetic field vector. Since the electric and magnetic field vectors are always perpendicular to each other, then the magnitude of the Poynting vector can be written in the following form,

$$S=EB/\mu_0 \quad \text{or} \quad S=E^2/(\mu_0 c) \qquad (2)$$

The actual intensity of the electromagnetic wave, I, is defined as the time average of S, taken over one or more periods, that is,

$$I = S_{ort} = \frac{E_{max} B_{max}}{2\mu_0} = \frac{E^2}{2\mu_0 c} \qquad (3)$$

It is now obvious that the definite wave intensity, I, is directly proportional to the square of the electric field vector.

The Malus's law is, on the other hand, explains the polarization of the light, passing through a simple polarizer. Basically, any polarised light going through a second polarizer/analyser with an orientation angle of, with respect to the original polarisation direction, then the phenomena is resolved by the Malus's law. The intensity of the light that passes through the polarizer, that is polarised light, is denoted by I_0, and the intensity behind the analyser is denoted by I. Considering only the electrical vectors, the relation between the original incident wave that is unpolarised, E_0, and the polarised wave that is E, can straightforwardly be given by,

$$E=E_0 \cos\theta \qquad (4)$$

where, as expressed before, denotes the angle between the orientation of the polarizer and the orientation of the analyser. Substituting the equation (4) within the equation (3) leads to the actual Malus's law that is expressed as

$$I=I_0 \cos^2 \theta \qquad (5)$$

The final equation modestly states that the transmitted relative intensity is directly proportional to the square of the angle between the orientations of the polarizer and analyser.

The He-Ne gas laser source radiates no polarised electromagnetic waves with a wave length of 632.8 nm. The polarizer is fixed vertically, that means the polarisation angle is set to be θ_0=0, and the light intensity behind the polarizer is fixed and measured to be I_0=714 lux. The analyser is stationary on the bench with a distance of approximately 10 cm and the angle of the analyser, that is, is simply varied with a precision angle meter and resulting transmitted intensity of the red light is measured by means of the light meter application. The outcomes of the measurements, namely, the angle of the analyser, transmitted intensity I, relative transmitted intensity that is I/I_0 and square of the angle $\cos^2\theta$, are tabulated in the Table 1.

In order to see the agreement between the actual theoretical Malus's Law, which is given in the equation (5) and the experimental data, relative transmitted intensity, is plotted as a function of the angle, given in the Figure 3. The experimental data is, in reasonably good agreement with the theory, within the limits of the experimental error.

In order to extract the actual trend of the experimental data, the transmitted relative intensity is also plotted as a function of the square of the angle, which is shown in the Figure 4. The experimental data at this stage is curve fitted and the outcome is expressed by y = 0.9177 x -0.0072 which is considered to be acceptable again within the limits of the experimental precision. It is obvious that the relative transmitted intensity is almost linearly proportional to the square of the angle of the analyser with respect to the polarizer. The discrepancy is about 8% which is reasonably good for this level of teaching efforts.

Table 1. The outcomes of the measurements, the angle of the analyser, transmitted intensity I, relative transmitted intensity, I/I_0 and square of the angle $\cos^2\theta$ are given.

Measurement Number	θ(°)	I(lux)	I/I_0	$\cos^2\theta$
1	0	714	1	1
2	10	593	0.83	0.96
3	20	569	0.79	0.88
4	30	472	0.66	0.75
5	40	351	0.49	0.58
6	50	278	0.39	0.41
7	60	133	0.18	0.25
8	70	79	0.11	0.11
9	80	24	0.03	0.03
10	90	0	0	0

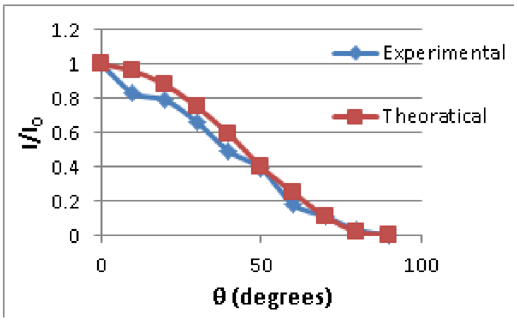

Figure 3. The experimental outcomes of the measurements and the theoretical expression of the Malus's Law.

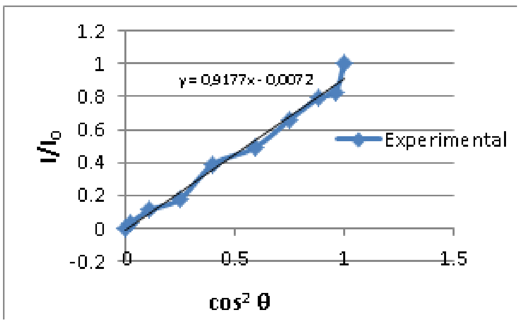

Figure 4. The transmitted relative intensity is plotted as a function of the square of the angle, curve fitted by y = 0.9177 x -0.0072.

CONCLUSION

As a conclusion, a very simple and inexpensive approach, employing only a smart phone, two polarisers and a laser/light source, is proposed for a better teaching environment and deeper understanding of confusing topics of Polarisation and Malus's Law. The performance of the apparatus is found quite good in the sense that the actual experiment could be repeated without any significant problems. The approach or teaching tool is specifically significant due to be based on a very simple apparatus which can be found in almost any physics laboratory and due to having great potentials to encourage and motivate undergraduate students to pay more and more attention to the difficult matter of Physics.

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