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Some Simple Experiments in Optics Using a Photo-Resistor

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Abstract. *A few simple and well-known experiments can be conducted in order to enhance further the student's grasp on the theoretical concepts. The main idea supporting these experiments is that the process of learning should be able to teach more than only reproducing and observing the physical phenomena. In this article we present simple experiments measuring light intensity and show how these simple experiments can be conducted in order to train and teach other concepts and capabilities far exceeding ones most obviously involved. The first problem presented to the students is that concerning the light detector. Our experiment uses an inexpensive, find to easy and trustable one. After initial calibration this detector is used to analyze the intensity behaviour of a point source with distance, Malus' law and the intensity profile across a diffraction fringe. Data treatment explores linear and exponential graphics comparing their features. We present procedures and results obtained with this simple experiment sand discuss them and their validity.*

Keywords. Laboratory Teaching, Optics Laboratory, Optics Teaching, Simple Experiments.

1. Introduction

Nowadays, most countries are facing an increasing need for physicists and engineers since new technologies and their applications present an exponential growth. But, in general, most of those countries have not had a strong increase in the number of students looking for the so-called "hard sciences". In our university, the figures of the evasion from the four years undergraduate course of Physics are about seventy five percent. So, our teaching efficiency is quite low. Furthermore, there are still problems with those who succeeded on finishing their undergraduate courses: many of them do not have a good comprehension of practical or experimental problems. The knowledge transference from theory to day-to-day life problems is very scarce if there is any at all. We can attribute these difficulties also to a deficient laboratory teaching. One of the possible solutions would be a development of small and cheap laboratory experiments and their application to training and demonstration with students [1, 2]. So the scope of this work is contributing with a cheap and easy way to do teaching experiments, in order to interest more students to persist and progress in Experimental Physics and, particularly, Optics. In Optics Laboratory teaching a recurrent problem is the measurement of light intensity. Several experiments depend on a fair evaluation of irradiances. We can cite a few among the most important: Point Source Irradiance Inverse Square Law; Malus' Law; Irradiance from a Cylindrical Lens. We named just these because they are among those most basic experiments in Optics Laboratory and the irradiances to be measured are quite high. Therefore we are just limiting the scope of this work to the experiments in which we can verify laws and behaviors with relatively high intensities. The scope of this work is to provide teaching laboratories with a cheap and powerful tool in order to proceed to experiments otherwise impossible to be made. Furthermore, mounting, calibrating and using this simple component, a photo-resistor, forces the students to learn important laboratory techniques and to develop the necessary patience and determination in order to obtain results with good level of accuracy. Two experiments are proposed in this work: Verification of the Point Source Irradiance Inverse Square and Malus' Laws. These experiments are basic in Optics teaching laboratory [3] and are fundamental for the scientific learning of the students. The scientific learning and the formation of a scientific spirit [4] is more important than only reproducing

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some experiments passing by them almost like scenery seen from a train window.

2. Methodology and Discussion

The experimental schemes for all of these experiments are well known, therefore due to this article space limitation we do not present them limiting ourselves to the results, which must be graphically presented.

2.1. Choice of an irradiance detector and its calibration procedures

The choice of a common photo-resistor was supported by a number of reasons: price, easiness to find them; it is practically foolproof; simple circuitry and a fairly good linearity (although over small regions). On the other hand they present some inconvenient aspects like: nonlinear dynamic range; slow response to intensities; nonlinear spectral response, which is much similar to that of human's eye. This scenario makes for a good place to start, setting the stage for building and understanding more complex experiments and procedures. The first question is how to conveniently mount the photo-resistor in order to detect intensity changes. The easiest way is simply measure changes in the photo-resistor internal resistance. One needs only an analogical or digital ohmmeter and measures the internal resistance variations of the photo-resistor. It is necessary to assume the ohmmeter scale is fair calibrated or execute its calibration. We think this step can be circumvented provide that students are warned about that. The electrical scheme of mounting can be seen in any good basic Physics book. The next step towards the Optics experiments is to calibrate the photo-detector response to incident intensity. The photo-resistor response also is opposed to the common sense of the students, that is, instrument readings are smaller for larger incident intensities. Therefore, the problem is to be sure the incident intensities vary linearly or with some well-known function, which can be fitted from experimental data. One can use some set of photographic neutral filters, or a graduated variable intensity filter, which, of course, are not easily available. A homemade solution is using a set of microscope slides. Each slide reflects about four percent of the incident light in the first surface and more four percent of remaining light. Therefore, one can plot the function of light intensity against number of microscope slides and use it to calibrate the photo-resistor against intensity. By the other hand, if one has a calibrated photo-detector like a silicon photodiode, he could use a much simpler mounting. Two polarizer filters can be used to grade incident intensities, which can be simultaneous (or not) monitored by the photo-detector. This is true for normal incidence and a 1.5 refraction index glass [3, 5] and we assume the light absorption is quite small compared to the reflection in the dielectric boundaries. However, as we are interested only in the functional behavior of our light "filter" and not in absolute values of intensities we can consider these values quite good for our experiment. An extension of this experiment would be to measure the refraction index of microscope slides and calculate the reflectance with measured value. Afterwards the students should calculate the mismatch between first figures and those from measured values. Surely, they will conclude that the errors the first procedure could introduce in the experiment are negligible. The conduction of the experiment will depend on the scope, time and available equipment. It can be conducted without leaving anything to chance or following to the verification of hereinabove named laws without the same strict regard to precision. In a laboratory with more resources a set of neutral filters with stepped intensities could be used or a variable neutral density filter. A low cost car stoplight incandescent lamp was used for this calibration. The incandescent lamp has a spectral emission curve much like of a blackbody at the same temperature, therefore it couples quite well with the spectral sensibility curve of the CdS photo-resistor. Nevertheless, the great infrared emission of incandescent lamps will pose some problems in the verification of Malus' Law. An experimental curve of the spectral sensibility of CdS photo-resistor should be made, but a bit more sophisticated equipment must be used in order to have a trustful result.

2.2. Verification of the inverse square law for the irradiance of a point source

Despite that this experiment is quite simple some attention must be paid to a few details in order to have experimental results consistent with theory. Correct alignment of all components is very important because detector will be displaced during the experiment. To a more precise experiment the light from a 300-watt lamp taken from an overhead projector is focused onto a variable diaphragm aperture and later strikes the photo-resistor. This is order to have enough light striking the detector still when the aperture of the diaphragm is very small and more similar to a real point source in the laboratory physical limits. Distances between diaphragm and photo-resistor are measured with a scale. A few attempts must be made in order to verify the amount of error introduced by increasing source diameter. One must consider whether the illumination system presents a focusing apparatus or not. If yes, this will distort the result as long as the wave front can have a negative vergence, a positive one or still no vergence at all. But, with a less demanding experiment an incandescent lamp of a car stoplight can be used with the advantage of low cost and low heat generation.

2.3. Verification of Malus' Law

This verification is a little simpler than the preceding ones. The polarizers are the usual ones used in photography and are mounted in a support with a goniometer. The polarizer are aligned in order to deliver the maximum irradiance, afterwards the direction of one is changed in five degrees steps from zero degrees to one hundred and eighty degrees. One can tabulate the results, calculate the cosine of those arcs, square them and make a graphic of intensity against square cosines. It is convenient to normalize the measured intensity values and trace a theoretical curve to compare with the experimental one. Another kind of graphics can be made to facilitate the comparisons, for instance, intensities versus square cosine and so on. In the measurement, special attention must be paid to the background infrared radiation since the normal polarizers do not act on infrared radiation. Once again, depending on the laboratory resources, a heat filter can be used or one can be improvised with water [6].

3. Results and discussion

3.1. Photo resistor calibration

Figure 1 presents theoretical, experimental and an adjusted function curves for the light transmission against intensity. Experimental data were normalized for easiness. The theoretical curve was calculated using an estimated 4 percent transmission to each air/glass or glass/air boundary for normal incidence. The experimental curve was obtained using a calibrated photo-detector and one can see from the graphics that experimental data show good agreement with the theoretical ones. Therefore, microscope slides filter can be used safely to calibrate other detectors like a photo-resistor.

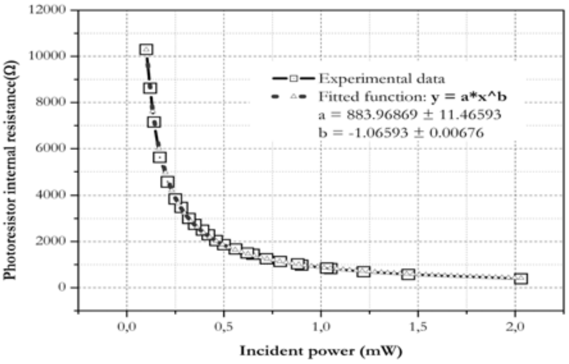

Figure 1. Transmittance x Number of added reflecting interfaces

The adjusting function $y = e^{-0.03835*x}$ will provide a good help acting like a mathematical filter for the data obtained with the unknown photo-detector. Therefore, it is of the utmost importance to have a filter with a well-known transmission function. It will liberate one from the uncertainty about detector function response to intensity. But, it is important to remember that all this procedure will permit only qualitative measurements, not the quantitative ones, that is, it does not permit to obtain absolute values of incident power.

Figure 2 shows the results using a more complex scheme with a power detector, polarizer filter set, power monitoring by a fixed (50/50) beam splitter and a silicon photo-diode.

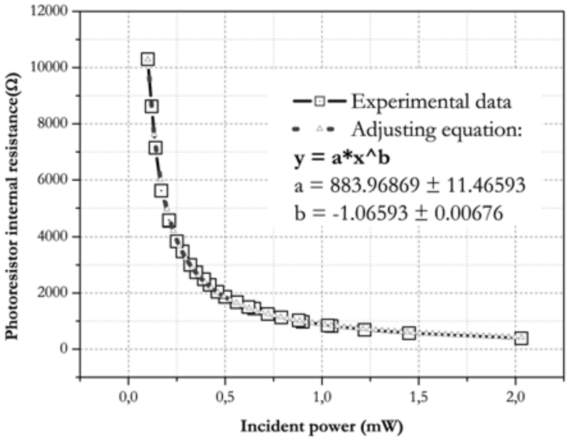

Figure 2. Photo-resistor internal resistance x Incident power (reduced range)

The graphics has been elaborated using the *OriginPro*^{TM} 7.0 Server. As the photo-resistors present strong nonlinearities at both high and small incident power since they have a constant minimum internal resistance and that evolutes almost exponentially with very low incident power we limited the operational range of our photo-resistor to 0.1 to 2.0 mW of incident power. In spite of that, it is clear that the photo-resistor have a good linear response only in the range of about one to two mW of incident power.

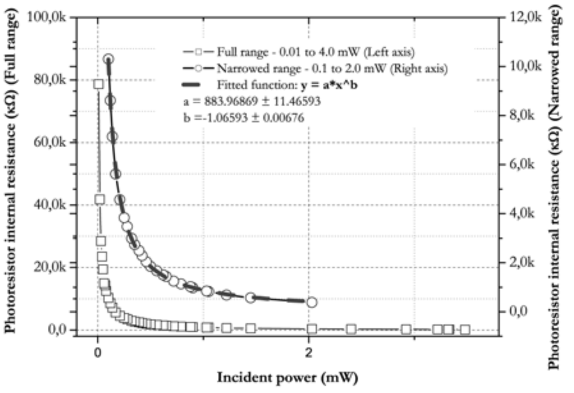

Figure 3. Photo-resistor internal resistance *versus* incident power (full and reduced ranges).

Nevertheless, one can divide in small sectors and in each of them the photo-resistor will present a quite linear behavior. Besides that, the adjusting function $y = 884 * x^{-1,07}$ can be used to correct the measurements made with this photo-resistor in the presented range. With this curve the student can transform his/her measured values in power figures. So, absolute measurements can be performed using the graphics presented in Figure 2. In order to get a better comprehension of the problem, Figure 3 presents the photo-resistor full range measurements comparing it with the smaller portion we have assumed for better accuracy. One can observe the quasi divergence of the photo-resistor internal resistance at low (< 0.1 mW, typically) and a flat behaviour at large powers (> 2.0 mW)

3.2. Verification of the Inverse Square Law for the irradiance of a point source

Figure 4 shows the result of photo-resistor application in the determination of the behaviour of a near punctual light source with the distance. The point source used was a common car stoplight lamp. We have preferred to use this one because of its friendliness: it is cheap, easy to find, easy to mount and turn on. We did not worry to focus the lamp light in an iris diaphragm in order to obtain a much more punctual source and the reason for that is the small power of the this lamp. In spite of these unforgivable imprecision in the experiment assembly, the result is quite consistent with the theory.

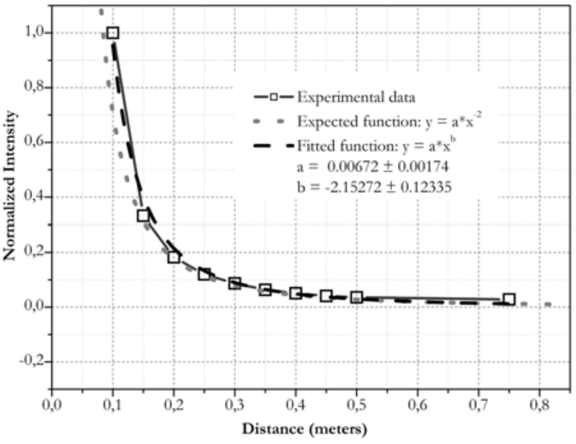

Figure 4. Inverse Square Law verification.

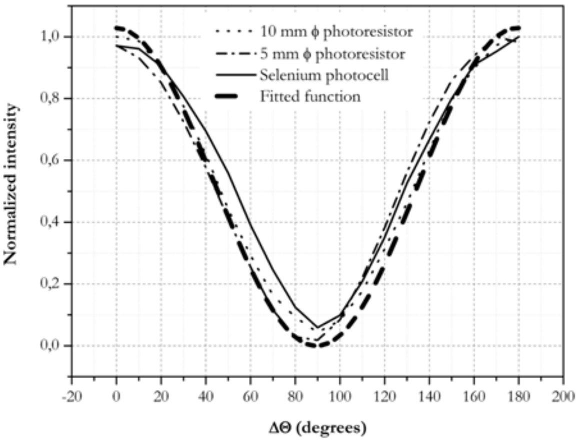

Figure 5. Malus' law verification.

That can be seen from the fitting function for the experimental data, $y = 0.0067x^{-2.15}$, which has a good agreement with the real dependence $y \propto x^{-2}$. A larger number of experimental points would be better for a more precise reproduction of intensity behaviour at small distances to the source, that is, in the interval between 0.1 and 0.3 meters. This discrepancy at smaller distances can also be attributed to the real dimensions of the source, which is minimized at larger distances.

3.3. Verification of Malus' Law

Figure 5 presents the results obtained for the Malus' Law. In this experiment, two photo-resistors were used and also a selenium photocell, which delivers a few mA current when illuminated.

This last one was used only as an additional reference. One can see from the graphics that the best result is obtained with the 5 mm diameter photo-resistor. As expected, the best agreement between theoretical and experimental curves occurs in the regions in which the incident power is larger, that is, there is a discrepancy in those curves when the incident power values tend to zero. Surprisingly enough, both photo-resistors present more accurate results than those of the selenium photocell. We believe with a little more effort these results can be still enhanced but the clear dependence of experimental data with the theoretical curve is noticeable and the fitting function below confirms that:

$$y = A\{\sin[\pi(x - x_c)/w]\}^2; \text{ with}$$

$$x_c = 89.55408 \pm 0.68404;$$

$$w = 180 \pm 0 \text{ and } A = 1.02834 \pm 0.01323$$

4. Conclusions

We have shown how a few interesting and involved experiments with light can be performed using cheap, easy to find components. Furthermore, these experiments can be tailored to the audience, in accordance to the students' general level of knowledge. There is still room for other experiments looking for improving the results and figures presented in this article, but not only that. Experiments to determine the photo-resistor internal resistance dependence with incident light spectrum are very promising and can lead to other interesting experiments and so on. Effectively, there is no dead end for the experimentalist. For the college students work to enhance the results and pursue a better data treatment using some convenient software can be very rewarding. Nowadays we have also to develop the student skills in dealing with informatics but not only that! Our vision is that the best way is to ally laboratory work with data treatment and simulation.

5. Acknowledgements

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6. References

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