Teaching Experimental Optics for Undergraduate Students in COVID-19 Times

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2021 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC) | 978-1-6654-4015-8/21/$31.00 ©2021 IEEE | DOI: 10.1109/IMOC53012.2021.9624832

***Abstract*—This work presents a viable alternative to Experimental Classes of Optics subjected to social distancing posed by COVID-19. The proposed experiments of Geometrical and Wave Optics can be conducted by the students in a home-lab basis with materials and equipment easily available. In the event of any occasional lack of these resources, an strategy was thought allowing the students to fulfill the objectives of the academic discipline.**

Keywords—home experiments, social distancing, education during pandemic

I. Introduction

Since the beginning of 2020, the world scenario has dramatically changed due to the spread of Coronavirus 2019 pandemic (COVID-19). A particular activity strongly impaired was Education, mainly to the social distancing rules posed by the airborne contamination [1].

While theoretical courses benefited from the possibility of remote access by internet to teaching platforms and social media, the realization of experimental activities revealed itself a challenging task [2]. Some alternatives emerged in an attempt to prevent the courses delay caused by the suspension of experimental classes.

A possible approach to deal with the problem was to limit the access to the laboratory, dividing the students in small groups to conduct an experiment and broadcast it live to the other groups, alternating the group every week [3].

In another attempt, first-year students were given a small kit enabling them to perform simple home experiments, preparing for a possible return to face-to-face lab sessions in the event of a pandemic regression [4].

In this work, we propose a set of Optics Experiments in a Home-Lab (OEHL) for an undergraduate Physics students, comprised by basics experiments covering Geometrical Wave Optics. The lab activities can be conducted by the students at their homes with minimum equipment requirement. An strategy considering a possible lack of even these simple experimental resources was thought. The proposed activities provide the students with the knowledge of experimental methods and data analysis. Besides, they are prepared for professional practice by gaining experience in alternative techniques for teaching experimental physics.

II. Sketching the Course

A. Learning Management System

The virtual education platform chosen to host the OEHL was Google Classroom. All the experimental asynchronous activities, instructions and complementary files were stored and gradually made available for the students along the course. The lab reports written by the students were also delivered and managed by the same platform. Synchronous activities were carried out by means of Google Meet platform.

B. Selecting the Experiments

Within the OEHL syllabus context, a list of possible home-available instruments and equipment was drafted. Light sources as flashlights, spotlights, bedside lamps and laser pointers were first considered. Simple optical instruments as plane mirrors, concave mirrors for makeup & shaving, reading magnifiers and lenses as well as compact discs (DVD or CD) were also taken in account. A simple positive thick lens can be built with a transparent cylindrical glass filled up with water. Substitutes for single and multiple slits comprised of a cut in a piece of cardboard made with sharp utility knife or box cutter showed to be a good choice. Other possibility was to produce a candle soot film on on a microscope glass slide cleaned with alcohol and held on the candle flame. After the soot deposition, slits can be made by removing straight lines of the film with the aid of a needle or a pin.

Taking in account the possible homemade optical equipment, the elected list for the OEHL was: (1) Focal length of a positive lens; (2) Single slit diffraction; (3) Double slit interference and (4) Diffraction grating. In order to better prepare the students for a future professional practice as teachers, an individual experiment proposition to be performed by every student was included.

C. Configuring the Course

The OEHL philosophy was to prefer quantitative experiments instead of demonstrations. To make it possible, two open-source software were recommended for the students: ImageJ [5] allowing to extract quantitative data from interference patterns and SciDAVis [6] for graphical and statistical analysis.

Despite the experiments were conceived with material of easy access, a set of data previously acquired relatively to each experiment was supplied for the students that declared not to be able to conduct an experiment due to unavailability of equipment. These data should be used as source for a "virtual" experiment to be analysed and reported as if it were a real remote experiment. To compensate for the lack, the students which fit that case were asked to include in their reports a critical review of a scientific paper previously selected and related to the subject of the experiment.

The activities were distributed alternating every week between experiments (as asynchronous activities) and synchronous discussions with the students along 12 weeks.

III. The OEHL Resources

The instructions and resources related to each experiment were made available for the students as the course evolved. The guidelines to be followed in the first experiments were

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given with more details, and then gradually replaced by more general instructions, allowing the students to further develop their skills. The guidelines for the four proposed experiments as described in the sequence.

A. Focal Length of a Positive Lens

Fig. 1 shows the proposed experimental setup using a glass of water acting as a cylindrical positive thick lens, focusing the light from a flashlight on a screen .

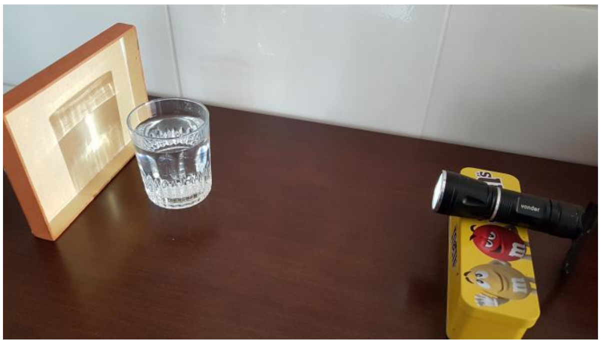

Fig. 1. Setup for the measurement of the focal length of a positive lens.

The students are instructed to use the basic form for a thin lens (1) as an approximation for the experiment, and compare the error resulting from not using the equation for a thick lens (2) surrounded by air [7],

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} = (n_l - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad (1)$$

$$\frac{1}{f} = (n_l - 1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n_l-1)d_l}{n_l R_1 R_2}\right] \qquad (2)$$

Where f is the focal length, s_o and s_i are the object and image distances, R_1 and R_2 are the curvature radius of the spherical surfaces, n_l and d_l are the refractive index and lens thickness.

The experiment comprises the graphic (with the aid of SciDAvis) determination of the focal length f by the method of conjugate points, where an adequate number of pairs (s_o, s_i) are measured to plot a graph of ($1/s_o$) in the Y-axis against ($1/s_i$) in the X-axis. Students are also advised to take in account the importance of the experimental uncertainties [8], presenting the graphs with error bars.

B. Single & Double Slits Experiments

A simple method for producing slits for diffraction and interference experiments is presented to the students. First, a microscope glass slide is sooted by moving the glass over the flame of a candle (Fig. 2.a). Afterwards, the glass slide is positioned between a pair of matches and a ruler is carefully positioned on them, without touching the soot. Finally, slits can be engraved by sliding a pin to remove the soot from the glass surface (Fig. 2b).

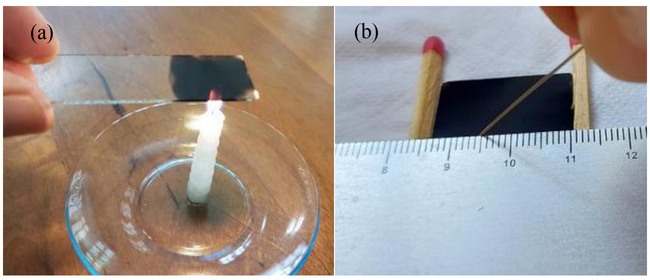

Fig. 2. (a) Sooting the glass slide surface; (b) Engraving a slit.

These slits can project an adequate diffraction-interference pattern onto a screen a few meters away, that can be measured with the aid of ImageJ software. Fig.3.a shows the obtained single and double slits, as well as the projected patterns (Fig. 3.b-c) of the slits under a green laser incidence.

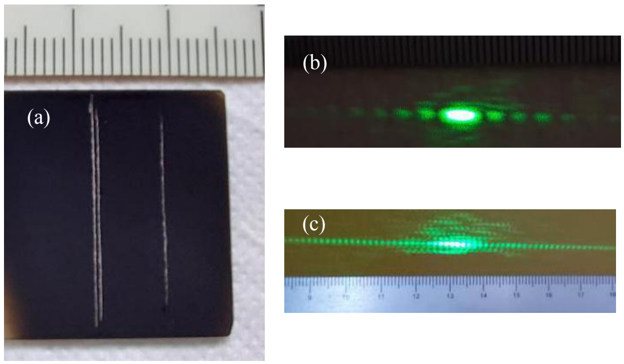

Fig. 3. (a) Double and single slits; (b) Single slit diffraction pattern; (c) Double slit interference pattern. The scales are graduated in mm.

As previously discussed, the images are supplied with scale allowing the students who can not conduct the real experiments to acquire the data. For these two experiments, students are required to determine the geometrical parameters of the single slit (width b) and double slits (distance a between slits), according to [7]:

$$b\,sin\,\theta_m = m\lambda, \quad m = \pm 1, \pm 2, ... \qquad (3)$$

$$a\,sin\,\theta_m = m\lambda, \quad m = 0, \pm 1, \pm 2, ... \qquad (4)$$

where θ_m is the angle position of a m-th minimum diffraction order (Eq. 3) or a m-th maximum interference order (Eq. 4), and λ is know laser wavelength. For these two experiments the geometrical parameters must be graphically determined with uncertainty analysis.

C. Diffraction Grating

The suggested setup for the diffraction grating experiments uses a DVD in reflecting mode. The first step consists on determining the grating period a (the distance between two consecutive data tracks on the DVD) by using a laser with known wavelength λ. Fig. 4 shows the setup, where the five diffraction orders ($m = 0, \pm 1, \pm 2$) are seen on the back wall. All the geometrical parameters, the associate experimental uncertainties and a scale (included in the picture) are supplied for the students unable to conduct the experiment by themselves.

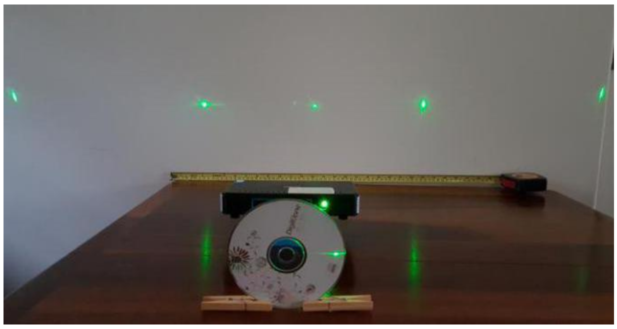

Fig. 4. Setup for determining the grating parameter a.

The next step in the experiment consists in replacing the laser by a white light source in order to determine the approximate average wavelength of the visible spectrum. The proposed setup using a LED flashlight as light source and two boxes lids to restrict the width of the collimated beam is shown in Fig. 5.a (top view) and Fig.5.b (side view). In Fig 5.c the resulting spectrum is also depicted, showing the m = 0 (white) and the m = +1 (colors) diffraction orders.

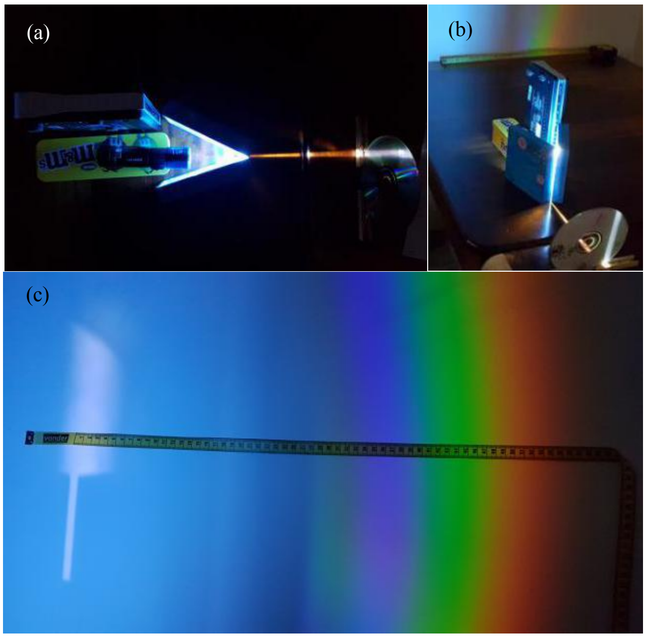

Fig. 5. Setup for determining the central wavelength of the visible electromagnetic spectrum: (a) top view and (b) side view; (c) the resulting diffraction pattern.

As the last experiment proposed, the students are required to determine the grating parameter *a* and the central wavelength of colors without supplying any further suggestion, as already pointed out in the beginning of Section III.

D. *Individual Experiment*

Along the OEHL course, the students are instructed they will have an additional experiment to be performed. They are expected to propose, build and conduct a quantitative experiment at home within the course syllabus, and present live their results at the end of the course.

IV. OUTCOMES FROM OEHL

The described OEHL was implemented in the undergraduate course of Physics for the academic discipline of Experimental Optics in the beginning of 2020 in Universidade Tecnológica Federal do Paraná, when the *in situ* classes were replaced by a remote regime due to the COVID-19. The format of the discipline changed in a few aspects since its begin, up the the third (present) edition.

One among the most important differences was the introduction of the possibility for any student, not able to conduct its own experiment, to perform a “virtual” experiment with the supplied data. This change was introduced still in the first OEHL edition, after the verification that not the majority of the students had a laser pointer to perform the experiments (2) Single slit diffraction, (3) Double slit interference and (4) Diffraction grating.

The Individual Experiment (described in Section III. D), first introduced owing to the lack of an experiment related to Electromagnetic Optics, also assured that all students would have to conduct at least one “real” experiment. In the first OEHL edition this experiment could be either demonstrative or quantitative. From the second edition on, the mandatory request for this experiment to be quantitative resulted in more elaborated works.

It is worthy to mention that the need for the Individual Experiment to quantitative led to an important change regarding the themes chosen by the students. Before the adoption of this measure, experiments were mostly related to Geometrical Optics (Laws of Reflexion and Refraction, mirrors and lenses), with an overestimated care with pictures and dedicating less importance to quantitative aspects. After these quantitative aspects became mandatory, the themes chosen by the students comprehend not only Geometrical but also Wave Optics.

Another result related to the change in the paradigm of teaching Experimental Optics posed by the need of social distancing during COVID-19 was the renewed interest of the students. The Physics undergraduate course in our Institution is primary devoted to form future teachers for Physics in High School. The students noticed a new methodology to introduce Optics experiments they could be able to apply once they graduate, even in colleges with little laboratory infrastructure. This unforeseen outcome reflected in a reduction in abandon of activities by the students before the end of the regular academic discipline of Experimental Optics, with an increase in their overall performances in the Course.

ACKNOWLEDGMENT

Authors thanks to the Universidade Tecnológica Federal do Paraná for providing the Institutional Google Classroom and Meet platforms, as well as the introductory courses about Google for Education used to carry out the teaching activities.

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