AN EXPERIMENTAL APPROACH FOR THE TEACHING OF GEOMETRICAL OPTICS

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Abstract: *The present work focus on the insertion of experimental classes in the teaching practice of Physics for Engineering. The need to stimulate the students to a favorable attitude in relation to a progressive construction of concepts through theorization and experimentation motivates this project. One of the experiments used during the Optics classes for Electrical Engineering at Univap is described here. The students's objective was to build up a benchtop imaging system. The imaging system employed is built with a set of two lenses. Parallel light rays from a laser source enter the system after passing through specially built masks that serves as objects to be imaged. The images produced by the mask are then magnified by the set of lenses. By using a collimated light source like a laser one can simulate the parallel rays that comes to us from far away objects like stars, planets or the moon. The objects to be observed through the imaging system were printed on two different kinds of transparences. This practice besides turn the Physics class more attractive can improve the learning process of many concepts and phenomena embodied in only one instrument or related to that, such as reflection, refraction, diffraction, transmission, etc. The influence of the lens focus, the aberrations and the effect of object position in the final image was studied considering the Gauss equation. The teaching process of such topics like resolution, size of the telescope aperture and magnification is also discussed.*

Key-words: *Experimental classes; Imaging system; Optics;*

1. INTRODUCTION

Sometime ago, the cost of laser equipment precluded their use in many simple teaching experiments. Beside their technical limitations, incoherent lamps had been employed for low cost teaching experiments. Nowadays, the widespread use of the laser technology forced a drop in the price of laser equipment, motivating a redesign of most teaching experiments to include such a powerful tool. Many experiments that were not possible of been performed in the teaching environment are now feasible and inexpensive.

In this work, we study a two-lens imaging system. The use of a collimated beam from a laser light-source stands as a simple way for the simulation of an object situated far away, at the infinity.

2. MATERIAL AND METHODS

A couple of lenses with focal distances equal to f_1 and f_2 was mounted in appropriate mechanical mounts separated by a distance ($f_1 + f_2$) in the configuration shown in Figure 1. The center of the lenses, as well as the respective focal points should stand along the symmetry axis of the system. Alignment tolerances are not critical for the purpose of the present work.

For each lens, a lens holder, a post and a post mount were used. An optical rail, with three rail carriers, was used for easy alignment of the whole system. Two rail carriers were used for the two lens mounts and the third one used to mount, and slide along the rail, the object to be imaged.

The object to be imaged was constructed by printing the character "F" with various sizes as a negative image onto two types of media: Hewlett Packard overhead projector transparences for ink-jet printers and conventional overhead projector transparences for laser printer and copy machines. The result was a mask, as shown in Figure 2, which the light should pass through. In addition, with the purpose of stimulating the students to play with the system in diverse circumstances and also to create beautiful color effects, color pictures of cells were also printed to serve as objects to be imaged by the telescope.

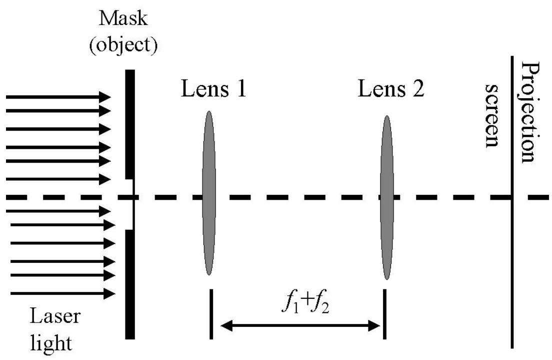

Figure 1. Experiment layout.

Figure 2. Mask in both Hewlett Packard overhead projector transparences for ink-jet printers and conventional overhead projector transparences for laser printer and copy machines.

A 10 mW helium-neon (He-Ne) laser was used as a collimated light source to simulate far away objects. A halogen lamp coupled into a fiber optical bundle was used to verify the effects that arises from the use of a non-collimated light source and, also, as a white-light source to watch the color pictures of the cells.

3. RESULTS

The first point to be noticed is the different optical behavior of the two transparent media used as substracts to print the masks. The overhead projector transparences of the type used for laser printer and copy machines present a smoother surface resulting in a more perfect mask. The transparences for ink-jet printers present a rough surface and significantly scatters the light. A sketch of those situation is displayed in Figure 3.

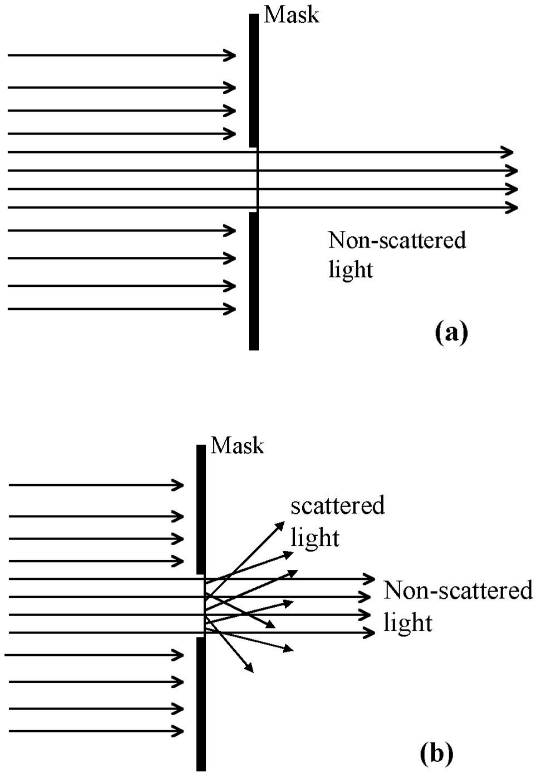

Figure 3. Mask made with conventional overhead projector transparences of the type used for laser printer and copy machines presents negligible scattering and approaches the perfect situation represented in (a) and the mask made with Hewlett Packard overhead projector transparences for ink-jet printers presents a significantly amount of scattered light (b).

The students are requested to mount and align the imaging system with the He-Ne laser. In the experiment logbook, it is stated that the objective of this phase of the work is to get familiar with optical prototyping and component alignment techniques.

After alignment, the mask having the character "F" stamped in negative image at the copy-machine type transparence sheet is placed in front of lens 1 and illuminated with the He-Ne laser. The 10 mW He-Ne laser had a beam diameter, visible to the eye, of the order of 2 mm, enough to cover the "F" character size of about 1,5 mm of the mask, without a beam expander. Students are requested first to note the inverted image produced by the imaging system, and then, to measure the magnification of the instrument by measuring the image and object size with a caliper. Magnification measurement was made on the basis of a best effort in view of the small size of the object. An optional magnifier lens could be used to improve the measurement of the "F" size. Next, the measured magnification M was compared to the theoretical value given by Equation (1):

$$M = -\frac{f_2}{f_1} \quad , \qquad (1)$$

where f_1 and f_2 stands for the focal distances of the lens 1 and lens 2, respectively.

We have used focal distances of 6cm for lens 1 and 30 cm for lens 2, resulting in a magnification M = -5, according to Equation (1). Beside the small size of the object, students' measurements for M agreed with the theoretical values within 15 %.

In the next step, students were oriented to watch the behavior of the image while sliding the support containing the image mask along the optical rail, starting from a distance to the lens 1 much greater then f_1, passing through the focal point of lens 1 and going through distances smaller then f_1. When the mask was illuminated by the collimated light from the laser, it was observed that the image size was invariant with the position of the mask, i.e. the object. The brightness of the image diminished for a longer mask distance to the lens 1 because the copy machine-type transparence sheet was not actually a scattering-free substract.

When the mask made with the copy-machine type transparence sheet is replaced by the mask made with the transparence for ink-jet printers, even under illumination with the He-Ne laser light the final image position and size produced by the instrument strongly depends on the mask position, and is given by the Gauss equation

$$\frac{1}{p} + \frac{1}{p'} = \frac{1}{f} \qquad (2)$$

which should be applied sequentially for lens 1 and then for lens 2, according to the theory developed in textbooks (HALLIDAY *et al*).

In light of the results we see that with a near-perfect mask, the image the light rays captured by the instrument to form the image are the collimated ones, while with the mask made with a scattering substract like the transparence for ink-jet printer, the image formed with the scattered light collected by the imaging system overrides the weak contribution of the parallel rays.

Such a results indicates that the use of the laser as a light source together with the mask made with a copy machine-type transparence was a good way to simulate far away objects, while the use of a mask made with a scattering substract allows the observation of the dependence of the image properties with the changing position of a nearby object.

At the end of the experiment, students are stimulated to play with the color picture of cells printed in inkjet-type transparence paper, by illuminating it with the white light delivered by a fiber optic bundle. For several object positions it is searched the proper position of the projection screen that results in a sharply focused image, and then check the validity of equation 1 applied in cascade for the two lenses.

4. CONCLUSION

With the use of inexpensive materials like overhead transparences for laser and for inkjet printers and a visible laser source, we could simulate a variety of situations for the object to be imaged by a two-lens system. Application of the experiment described herein in a teaching environment allows for the students the construction of several important concepts in geometrical optics, which are essential for the design of optical imaging instruments.

REFERENCES

HALLIDAY, D. *et al.* **Fundamentals of physics.** John Willey & Sons, Inc. 4th edition.