

Designing an Experimental Prototype to Support Geometric Optics Concepts Comprehension

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Abstract An experimental prototype to support the comprehension of concepts of Geometrical Optics was designed and assembled. The prototype might help teachers to explain Geometrical Optics concepts—for example, the behavior of light passing through converging and diverging lenses and optical instruments—it is an inexpensive and accessible device that can be transported to classrooms. The expectation is that the equipment, properly used by teachers, would lead the students to understand abstract concepts of Geometrical Optics and thus motivate them to study this science.

Keywords: *experimental prototype, geometrical optics, geometrical optics concepts*

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1. Introduction

Applying Geometrical Optics concepts has been very useful in everyday human activities such as the construction of telescopes, cameras and video cameras, microscopes and the like. On the basis of its importance, optical studies are permanently performed in industry and laboratories worldwide. Geometrical Optics is a component of the curriculum in many universities and colleges, especially physics and engineering. Many researchers have devoted their efforts to the task of facilitating conceptual understanding of optics through the use of accessible methods of learning, particularly in the experimental activities, because the understanding of the field of optics can benefit from laboratory experiments.

The proposed prototype [1] is integrally designed; all the basic components for demonstration and measurement are included and can be transported, accommodated and used easily and quickly. A wide range of experiments can be carried out by using the experimental prototype of Geometrical Optics, demonstration and measurement of optical objects are possible, e.g. light rays passing through divergent and convergent lenses, the laws of total reflection and refraction, Snell's law, angle limit, focal distance lenses, lens system, shaping images with converging and diverging lenses, plane mirrors, concave and convex decomposition and recombination of white light, Galileo's astronomical telescope structure, projector, magnifying glass and microscope; all integrated into a simple and easy to use single device.

2. Description

The invention herein proposed describes a portable modular device for Geometrical Optics lab practices

which comprises a container (Figure 1) which includes a number of components: light source a diversity of divergent lenses, cylindrical type divergent lenses, several convergent and divergent spherical type lenses; and a number of diaphragms of different types, such as diaphragm with images, diaphragms of apertures with different modalities such as image diaphragm, three slots diaphragm, or a single slot, etc. Figure 1.



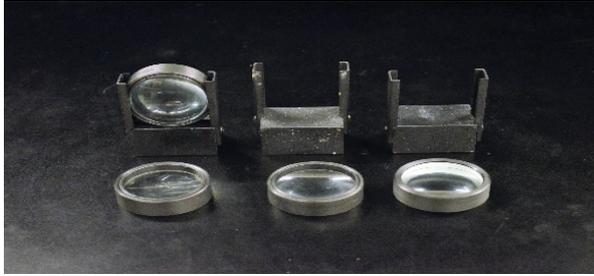
Figure 1. Components stored the prototype Geometrical Optics
Nomenclature of parts:



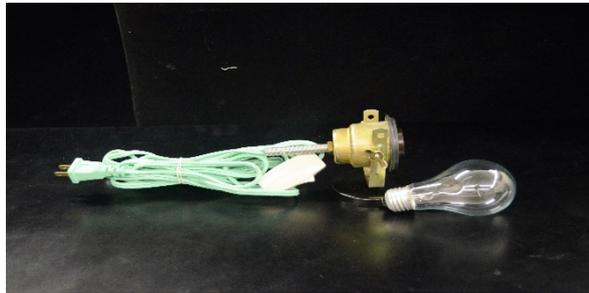
Components: Converging lens, Diverging lens, Semi-cylindrical lens, rectangular prism, trapezoidal prism, concave mirror.



Three slots diaphragms. Single slots diaphragms, Object slots diaphragms.



Lens mount: Converging lens $f = +30$ cm. Converging lens $f = +10$ cm, Converging lens $f = +5$ cm, Diverging lens $f = +10$ cm.



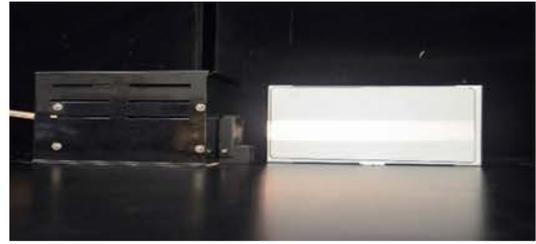
Lamp with horizontal filament into the socket.



Lamp, Housing, Filter cover

This invention was conceived to facilitate the implementation of Geometrical Optics experimental practices in the classroom, supporting theoretical concepts of physics where these issues can be illustrated. It is designed to solve the problem of inaccessible optical kits for its unaffordable cost and commercial availability. It is easy to assemble and requires limited technology, facilitating its commercial competitiveness and ease of application by educational institutions; besides it was conceived with the premise of having a comprehensive structure covering a wide range of optical components, it is a flexible device to which more compatible component might be added.

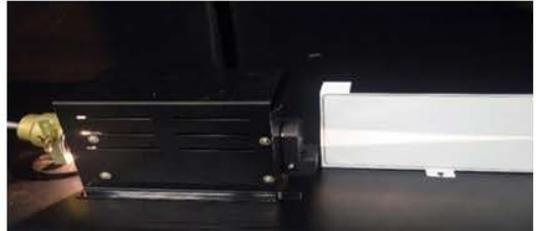
Many experimental tasks can be performed by using the instructional guide included in the Geometrical Optics prototype. The instructor will simply need to change the setting by placing the necessary components in an arrangement satisfying the requirements of the lesson.



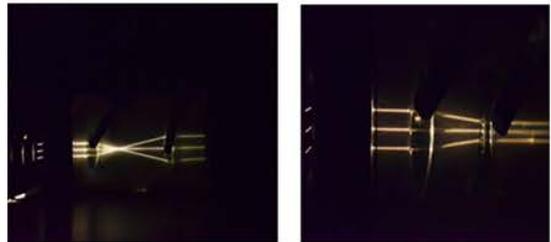
Experimental setup to get parallel beams (rays).



Experimental setup to get divergent beams or (rays).



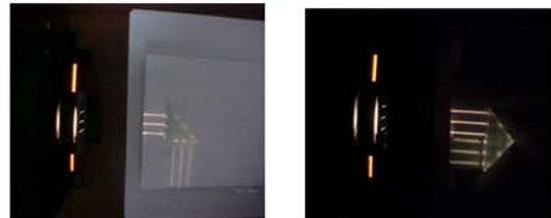
Experimental setup to get convergent beams (rays).



Lens system for demonstrations of Galilean telescopes.



Total reflection and critical angle.



Total internal reflection.



Experimental setup to get focal distance. the mirror concave and convex

Figure 2. A series of drawings illustrating practical activities of Geometrical Optics

This and other aspects of the settings are illustrated below and will be better understood by consulting the following descriptions and drawings accompany them. The reader should understand, however, that the following descriptions, while indicating the suggested configurations and numerous specific details are given as a means of illustrating the applications and not its limitation. Many changes and modifications may be made within the scope of the settings described herein without altering the original purpose and general framework for which the device was designed. Some examples (Figure 2) shows several Geometrical Optics practical activities illustrating an optical concept dealt in a particular lesson.

2.1. Description of Some Physical Concepts of Geometrical Optics Illustrated at the Preceding Figures

Geometrical Optics is based on the concepts of ray, index of refraction of materials (glass) and path or optical path of a ray through one or more materials. The function of Geometrical Optics is to analyze the physical problem of reflection or refraction of light in one or more reflective or refractive surfaces [2]. (Cornejo & Urcid, 2005).

That is, on the basis of Snell’s Laws of Reflection and Refraction, and with the help of geometry, formulas corresponding to the description of optical systems (lenses, mirrors and optical instruments) can be obtained [3]. (Hecht, et al., 1974).

Theoretically, an "optical system" is a combination of spherical and no spherical surfaces, possibly constructed

with materials of different refractive index. In this research only centered spherical surfaces with an imaginary axis (optical axis) joining the vertices of the surfaces in a straight line were considered.

A spherical optical system commonly used might be lenses, transparent objects (usually glass), limited by two surfaces (at least one of them is curved). They fall into two general classes according to the form they take: convergent (or positive) which are thicker at its central part and narrower at the edges; or divergent (or negative) thicker around the edges and thinner at its central part. [4]. (Educaplus, 2014).

Apart from these features, there are other features more relevant for all optical systems; these features are defined by the cardinal points, that is, two focal points, two main points, and two nodal points. All light beams parallel to the optical axis entering the optical system from left to right cross a point at the optical axis (called second focal point) when going out (Figure 3). If the rays entering and emerging out of the system are extended, as shown in dotted lines in Figure 3, they define a surface, usually called principal plane, and the intersection of this plane with the optical axis called second principal plane that intercepts the optical axis at a point called the second principal point.

Taking into consideration the procedure explained above the primary focal point and the first principal plane may be obtained, as the parallel light beams are now entering the system from right to left [5] (Smith, 2008).

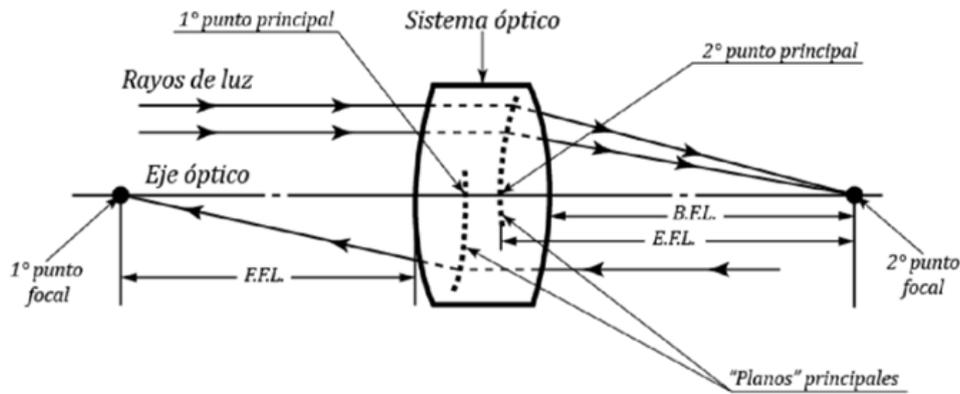


Figure 3. Illustration of the location of the focal points and principal points of a common optical system (Image taken from Smith, 2008)

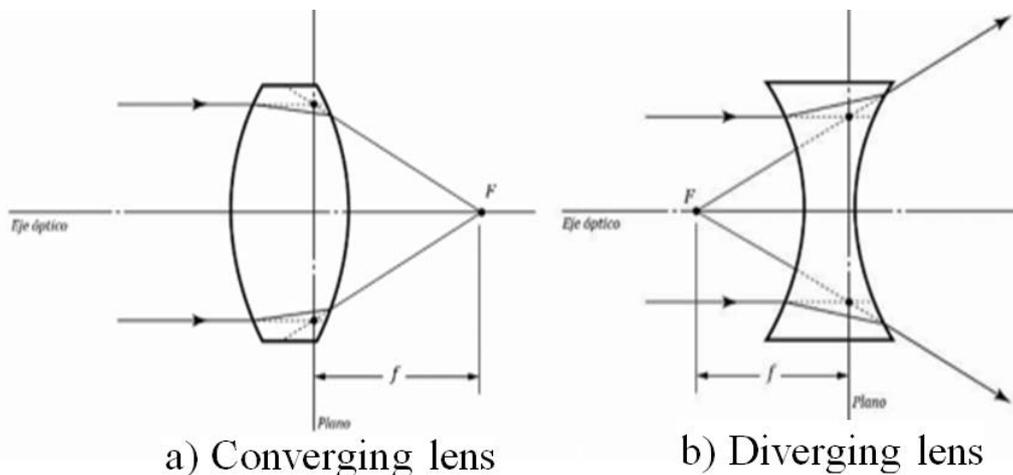


Figure 4. Focal distance of a lens: a) convergent and b) divergent

According to the above, we can represent geometrically the principal planes and principal points of a converging lens (biconvex) and divergent (biconcave) (Figure 4). The distance from the principal point to the focal point in respect to the optical axis is called effective focal distance or focus of lens f . (Figure 4a).

For a divergent lens like the one shown in Figure 4b, parallel beams going through the lens deviate or diverge, that is they never cross the optical axis as in the case of convergent lenses shown in Figure 3 and Figure 4. The second principal plane is obtained by the intersection of extended parallel rays with divergent rays as shown in the dotted lines shaping the principal plane (Figure 4b). This plane intercepts the optical axis at a point called second principal point.

To locate the focal point of a divergent lens the procedure is the following: if parallel rays going out of the lens deviate or diverge, they should be extended to the left side, as shown in the dotted lines of Figure 4b. They will intercept the optical axis at a point called focal point. The distance of the focal point to the principal point, in respect to the optical axis, is called effective focal distance or focus f .

2.2. Shaping Images by the Plotting Rays Method

Definition of principal planes: One may infer that if a ray cuts the primary principal plane at a height h , such ray goes out the optical system cutting the second principal plane at the same height h . Smith (2008).

Once the position of focuses and principal planes are known, we may attempt the graphical construction of an image (Figure 5) using the following rays:

- The ray that goes parallel to the optical axis, once refracted, passes by the focus image.
- The ray that goes through the object focus, emerges parallel to the optical axis.

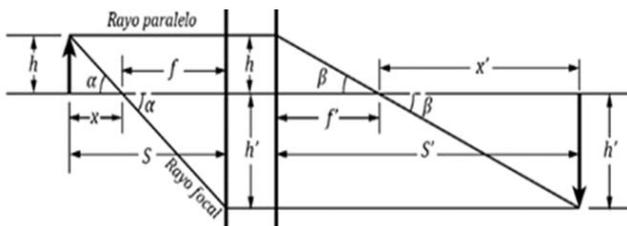


Figure 5. Size and position of an object h in an optical system

2.2.1. Luminous Rays

To carried out this experiment, the pieces of the prototype of Geometrical Optics listed below (Figure 6) were used: Lamp, filter cover, a converging lens $f = + 10\text{cm}$, three slots diaphragm, the screens place vertically, and the housing.

First step: To obtain divergent or convergent rays place a lamp with horizontal filament into the socket, just in front of the converging lens $F = + 10\text{cm}$ and a three slots diaphragm in a horizontal position. Three parallel light rays will be obtained on the surface of the rail of screen. For getting better results, adjust the tilt of the lamp and slide it through the axis guide at the housing either forward or backward. Rays become parallel by placing the filament in a given position in relation to the converging

lens $F = + 10\text{cm}$ (focal distance from the lens), being out of this position, the rays will converge or diverge, accordingly to the filament position.

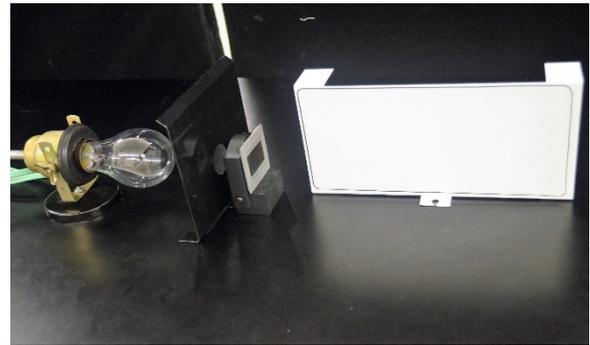


Figure 6. Light rays (with a lens)

2.3. Arrangement Getting Rays: Parallel, Divergent and Convergent Rays

For getting beams or parallel rays, the lamp filament, commonly called light focus should be placed at the lens focal distance illustrated in Figure 7.



Figure 7. Experimental setup to get parallel beams (rays)

For getting beams of convergent rays the lamp filament or commonly called light focus should be placed at a larger distance (focal distance of the lens over 10 centimeters, as shown in Figure 8).



Figure 8. Experimental setup to get convergent beams (rays)

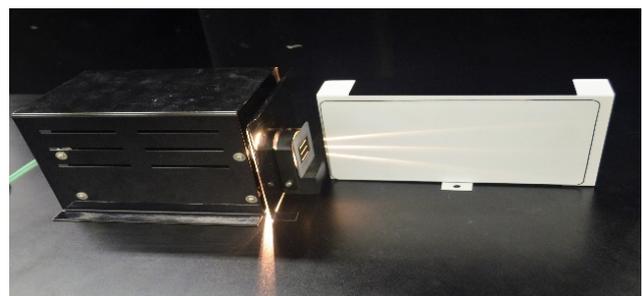


Figure 9. Experimental setup to get divergent beams or rays

For getting beams of divergent rays the lamp filament, commonly called light focus, should be placed at an inferior distance than the focal distance of lens (under 10 centimeters, as shown in Figure 9).

At this point, the experiment to find the focal distance of convergent and divergent lenses is carried out with the prototype of geometrical optics experimental set as described bellowed. With the experimental setting for parallel beams (Figure 7), place a convergent lens that disrupts the rays as in Figure 10 and observes the deviation of the rays converging and intersecting at a point called the focus of the lens interposed.

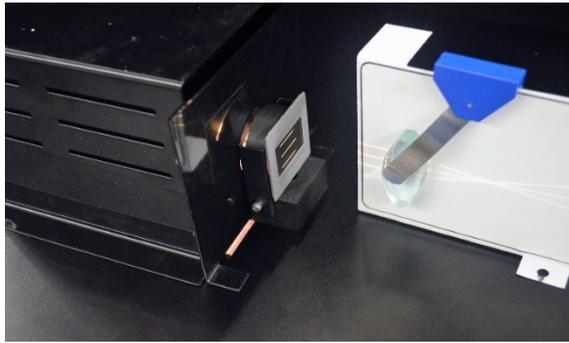


Figure 10. Experimental setup for the focal length of a convergent lens

With the same setting of parallel beams (Figure 7), place a diverging lens and observe the deflection of the rays do not intersect, i.e. they diverge, but by prolonging to the left side of the lens, these divergent rays would intersect at a point called focal distance (Figure 11).

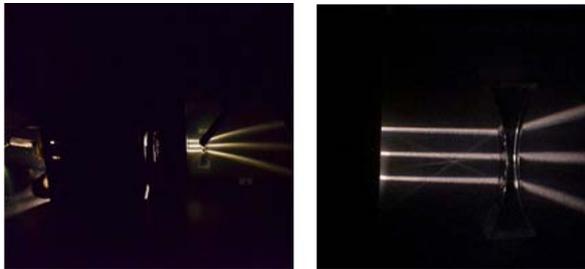


Figure 11. Experimental setup to obtain the focal distance of a divergent lens

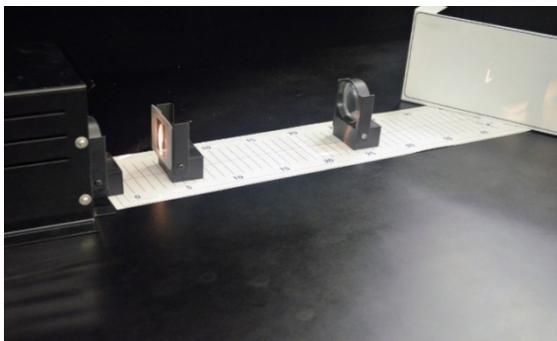


Figure 12. Experimental setting to obtain the shaping of images with a convergent lens and the focal distance of a lens

To shape images with convergent requires a certain position of the object in respect to the screen, and locating the position of the image resulting from the convergent lens. From equation (2), the variables s and s' and f are obtained, determining the distance s of the object position in respect to the lens, the distance s' of the image position

in respect to the lens, and the focal distance f of the lens. By applying this equation, if s and s' are known, the value of f (focal distance of the convergent lens) can be calculated. To prove what has been said before, the following experimental setting may be completed (Figure 12).

Once the setting illustrated in Figure 12 is completed, the distance between the lens and the object located at a graduated scale base is measured. This distance represents the position of the object in relation to the lens in equation (2), it represents the value of s . Then the position of the image on the screen is measured in relation to the lens and represented as the value of s' . Using these values in equation (2) will result in calculating the value of the focal distance of the lens as a procedure to verify the value of the focal distance of the lens to be proved.

Figure 13 shows a setting where the value of s is truly inferior as compare to the value of s' , thus the size of the image increases. Keep in mind that the value of s should not be less than the focal length of the lens, as it will not form a real image on the screen (the image would be a virtual image).

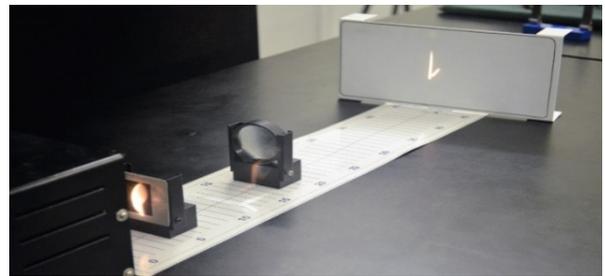


Figure 13. Experimental setup for obtaining the shaping of images with a lens

The Experimental applications herein described, using the Geometrical Optics experimental equipment proposed, allowed to illustrate how to prove experimentally the theoretical notions related to the focal distance of convergent and divergent lenses and the shaping of images.

3. Conclusions

Geometrical Optics experimental equipment proposed in this article can be of great help to the teacher in the classroom because it allows simultaneous experimental demonstrations and validation of the theoretical notions he is explaining. The proposed experimental equipment can be used by both the teacher and the student as its versatility of handling equipment does not require much instruction. Moreover, the equipment was designed and assembled experimentally together with a user's manual providing sufficient guidance and detailed descriptions of experiments related to the notions of optics.

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