Some remarks on using the principal rays for teaching the elementary optics

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Abstract

The purpose of this study is to put forward the conditions under which the principal rays are valid through experiments by means of discovering the paraxial rays. The result of this study suggests a true understanding of the valid conditions for use of principle rays and the reasons of obtaining more than one image during the experiments conducted with nonparaxial rays. This experiment may be used for showing the condition of paraxial ray before stepping into image formation through principle rays.

Keywords: principle rays, paraxial rays.

Resumen

El propósito de este estudio es presentar las condiciones en que los rayos principales son válidos a través de experimentos por medio del descubrimiento de los rayos paraxiales. El resultado de este estudio sugiere una verdadera comprensión de las condiciones válidas para el uso de rayos principio y las razones de la obtención de más de una imagen durante los experimentos realizados con rayos nonparaxial. Este experimento puede ser utilizado para mostrar la condición de rayos paraxiales antes de entrar en la formación de imágenes por rayos principio.

Palabras claves: rayos principio, los rayos paraxiales.

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I. INTRODUCTION

In spherical mirrors, there are two laws for the reflection of the rays in order to determine the location of the image. These laws are; a ray that is initially parallel to the central axis reflects through the focal point on the central axis [1, 2]; a ray reflects from the mirror after passing through the focal point emerges parallel to the central axis [3]. In most of the basic physics courses and textbooks, the rays obeying the two laws are mentioned as principle rays. However, the conditions under which those principle rays are valid are not emphasized. This situation leads the incorrect generalization of "the principle rays are valid in every condition". This study emerged through a high school student has proven the laws are indeed mistaken by drawing a spherical mirror in the form of semicircle to his physics teacher. In this study, the efforts will be made to put forward under which conditions these rules are valid through a simple drawing and an experiment.

II. THEORETICAL KNOWLEDGE AND PRACTICES

The principal rays mentioned above should be derived naturally by means of the second law of reflection. The second law of the reflection for spherical mirrors says that; when a line is drawn from the centre to the point where the incident ray strikes on the mirror, the angles formed by the incident ray and the reflected ray with this line are equal. At the same time, for the principal rays mentioned above to provide the second law of reflection for a ray requires certain circumstances in spherical mirrors. In other words, the principal rays are valid only under special conditions. These conditions are the situations when the light strikes almost perpendicular to the surface of the spherical mirror and all the light rays coming to the spherical mirror are near to the central axis.

The light rays coming to the spherical mirror under these conditions are called *paraxial rays* [1]. In order to explain this situation better, it will be useful to show the student's drawing on a graph paper where he used for proving that these rules are faulty below (Figure 1 inspired from ref. [3]. As known, spherical mirrors are the definite pieces of a

spherical surface. Therefore, we can use the surface of a sphere for showing these three reflections on the same ray (The rays labeled as 1, 2 and 3 in the figure 1 show the reflected ray obeying the second law of the reflection (1) and the first two-principal rays (2, 3)).

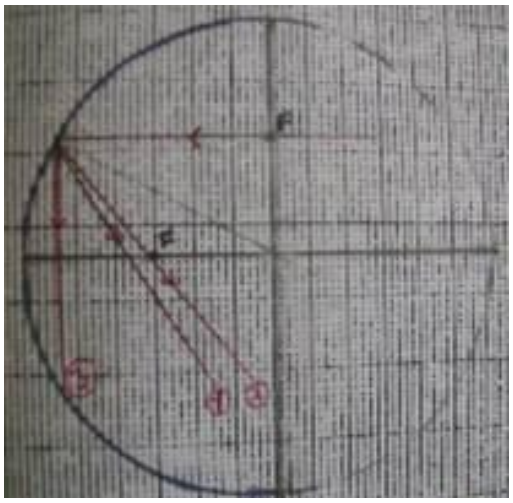


FIGURE 1. The reflections of the incident ray from the spherical mirror according to the principal rays and the second law of reflection -1.

In the above figure, a spherical surface is drawn and two central axes on the vertical and horizontal planes were determined according to upper and left semi spherical mirrors. The ray reflects from the spherical mirror after passing through the focal point (F) on the vertical axis parallel to this axis according to the second principal ray (given in ray number 3). At the same time, this ray must also be reflected through the focal point on the horizontal plane as it is parallel to the central axis on the horizontal plane according to the first principal ray (given in ray number 2). Besides these, also the second law of reflection can be used for drawing the reflection of the ray (given in ray number 1). All three reflections of this ray must have intersected in the same point on the central axis drawn for each rule when considering that the principal rays have thought to be valid for all circumstances. Nonetheless, as these rays did not intersect, we may state that these principal rays are not valid in these circumstances.

Now let us see that under which conditions the principal rays valid with a simple experiment for the incident rays those are parallel to the central axis and expected to pass through the focal point. We put the uniform semi circular metal plane whose inner surface reflects the light on a scaled paper. After that, we define the central axis and indicate the focal point(r/2) by means of a paper clip. Then, in order to obtain a single ray of light in the form of beam we place a single slit in front of the light source. Afterwards, as seen in the Figure 2a, we stroke the ray of light on the spherical metal plate parallel to the central axis. It is normally expected that the ray reflects by passing through the focal point according to the 1st rule. However, this ray does not pass through the focal point as it does not have the required conditions.

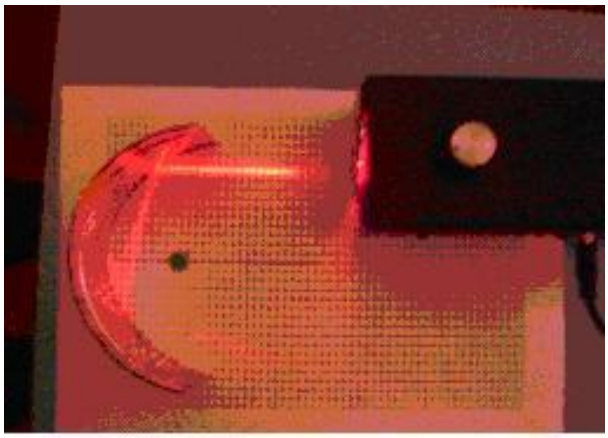


FIGURE 2A. The reflection of the ray sent parallel to the central axis in the spherical mirror– 1.

When we close the same ray to the central axis, we see that the reflected ray gets closer to the focal point (Fig. 2b).

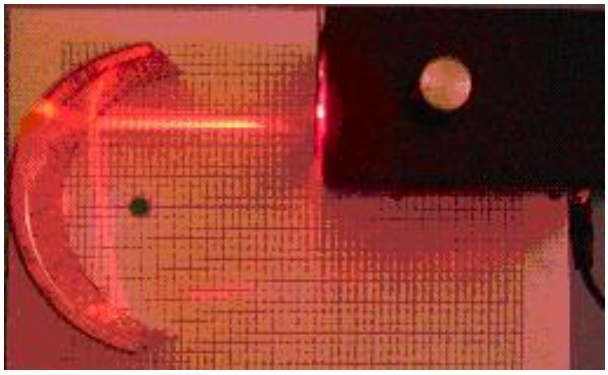
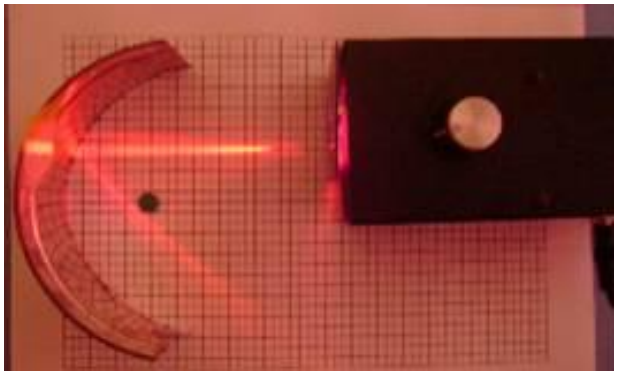
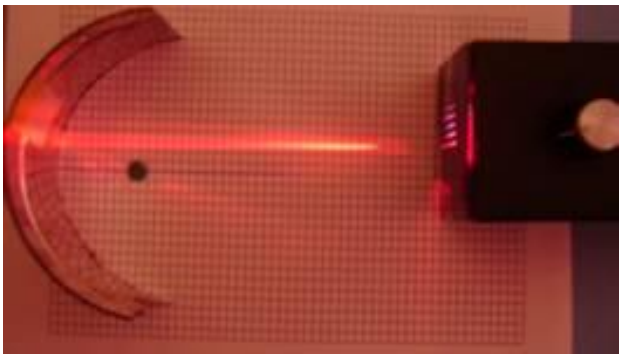


FIGURE 2B. The reflection of the ray -that is closer to central axis- sent parallel to the central axis in the spherical mirror-2. As we keep on closing this ray to the central axis, it is seen that the reflected ray passes through the focal point (Figure 2c, d). At that moment, the ray sent to the spherical mirror provides the conditions mentioned above.



(C)

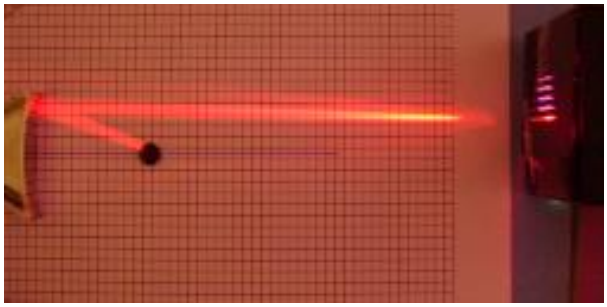


(D)

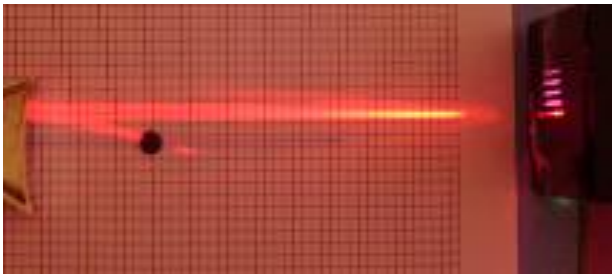
FIGURE 2C and D. The reflection of the ray sent parallel to the central axis in the spherical mirror– 3.

Now, there appears to be one more question to be answered; how it is possible for us to obtain correct images in the systems used during the experiments despite the fact that rays reflects differently? The answer of this question lies in the design of the systems we used either in the experiments or in the daily life which are constructed according to the conditions where principal rays are valid. If we examine the spherical mirrors used in the experiments (Fig. 3a, b), we see that those mirrors are composed from a little part of the spherical surface rather than the semi sphere and by this way the surfaces are located as the light almost strikes the mirror perpendicularly. In this case, no matter which part of the surface the light strikes on, it reflects from the mirror obeying the mentioned rules. These laws of principal rays are valid in practice and quite useful under these circumstances. In the systems which are not obeying these conditions the problem of **spherical aberration** [1] will occur. At that time, the problem of focalization will form of blurred image.

Now it is time to discuss how to accommodate the rays drawn in Fig. 1 to the conditions. It may be solved by sending the ray to the spherical mirror from a closer point to the central axis chosen in Fig. 1 by thinking that we use only a small part of the spherical mirror as the mirrors used in the practice and apply these three rules on scaled paper again (Fig. 4). The ray we sent, this time, passes through the focal point on the central axis after reflecting. As seen from the Fig. 4, the reflected rays pass through very close to the focal point for the three mentioned rules under these circumstances. That is to say, when applied under the appropriate conditions, these rules give almost true results.



(A)



(B)

FIGURE 3. The reflection of the ray sent parallel to the central axis in the spherical mirror in practice.

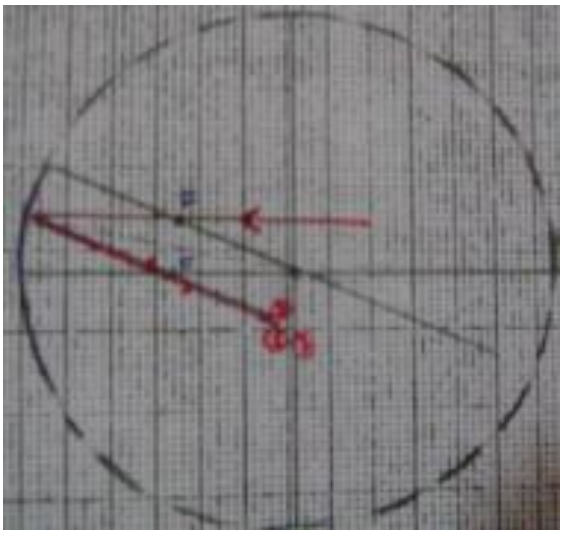


FIGURE 4. The reflections of the ray sent to the spherical surface according to the principal rays and the second law of reflection -2.

III. CONCLUSION AND RECOMMENDATIONS

The conditions for this principal rays are also valid for the systems of convex mirrors and lenses. It is suggested that while telling about the principle rays in the systems of mirrors and lenses raising awareness about the conditions under which these principles rays are valid should be paid attention. Moreover, the mirrors should be drawn in a way that their opening angles should be smaller. In addition to this, the students should be warned about the mistakes done in this subject. Otherwise, the students who discover this may either warn you or never takes heart to do that and lose their confidence in physics laws.

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