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Geometrical Optics

Experiment Conducted by Berk ARI
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Abstract:

In the conducted study, the measurement of the focal points, magnification of a convex lens, and radius of curvature of a convex mirror were undertaken with constant temperature and pressure. Multiple readings for the position of the incident and the distance between the object and the lens were taken. The average focal point of a convex lens was determined from the second part of the first method, along with its uncertainty, which was at $14.4 \pm 0.3\ cm$. The error in comparison to the literature value was calculated to be 4%. Additionally, it was discovered that The optical bench in the first part of the first method was unnecessary, as the focal point was measured without using it to be $15.5 \pm 0.05\ cm$.. The second method of the study involved measuring the magnification of the same lens, within the range of 0.35 to 2.7, by utilizing various objects. Lastly, in the third method, the radius of curvature of the converging mirror was measured to be 17.40 $\pm$ 0.003 cm. Throughout all the measurements, the lens equation (1) was used to determine the relation between the focal point (f), the distance of the source of light to the lens (D_i), and the distance between the object and the lens (D_0).

Introduction:

The aim of the experiment was to investigate equation (1), which proposed that different properties of focal points, magnification, radius of curvature and diffraction rates of light are exhibited by every convex or concave lens.

In the investigation, the property of the convex lens was observed to be the accumulation of light from the source at one particular point, known as the focal point, as illustrated in Figure (1).

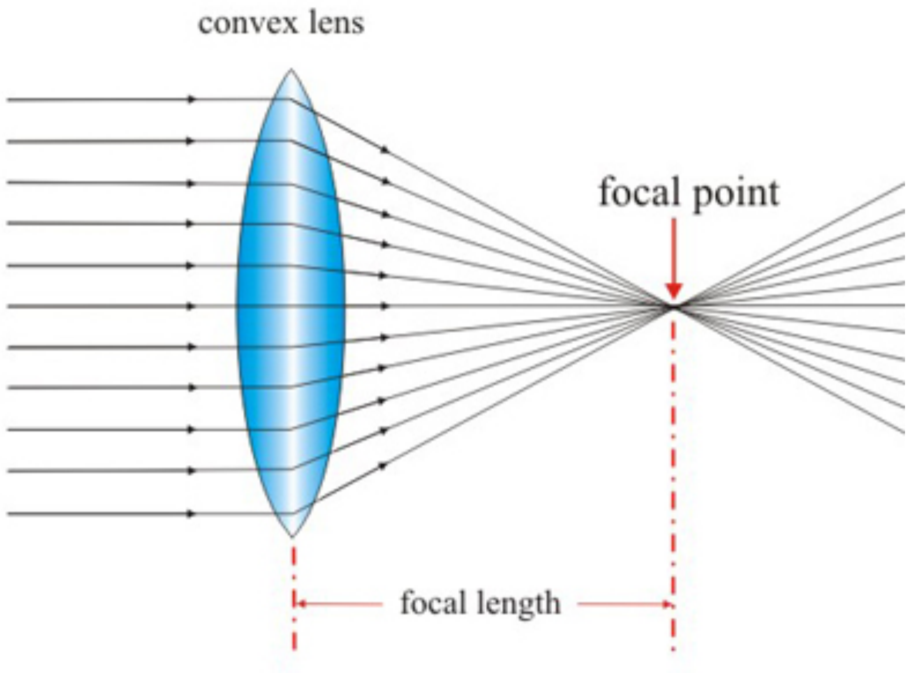

Figure 1: Shows the focal length and point of a convex lens.
(https://www.sciencelearn.org.nz/images/48-convex-mirror , 2024)

In order to determine the focal point of a convex lens, equation(1) was used in all parts of the experiment.

$$\frac{1}{D_i} + \frac{1}{D_0} = \frac{1}{f} \qquad (1)$$

Where D_i denotes the distance of the source of light to the lens (D_i), and the distance between the object and the lens represented by (D_0) , and f is the focal point.

The perception of an object is influenced by the diffraction of light rays, which alters the rate of magnification according to the degree of diffraction. This phenomenon was demonstrated in the study conducted, wherein it was observed that the perception of the object was modified based on the extent of diffraction experienced by the light rays. The rate of magnification was thus found to be dependent on the amount of diffraction that occurred, indicating that diffraction plays a crucial role in determining the perception of an object. The magnification can be calculated by using equation(2).

$$M = \frac{D_0}{D_i} \qquad (2)$$

Where M is the magnification, Where D_i denotes distance of the source of light to the lens (D_i), the distance between the object and the lens represented by (D_0)

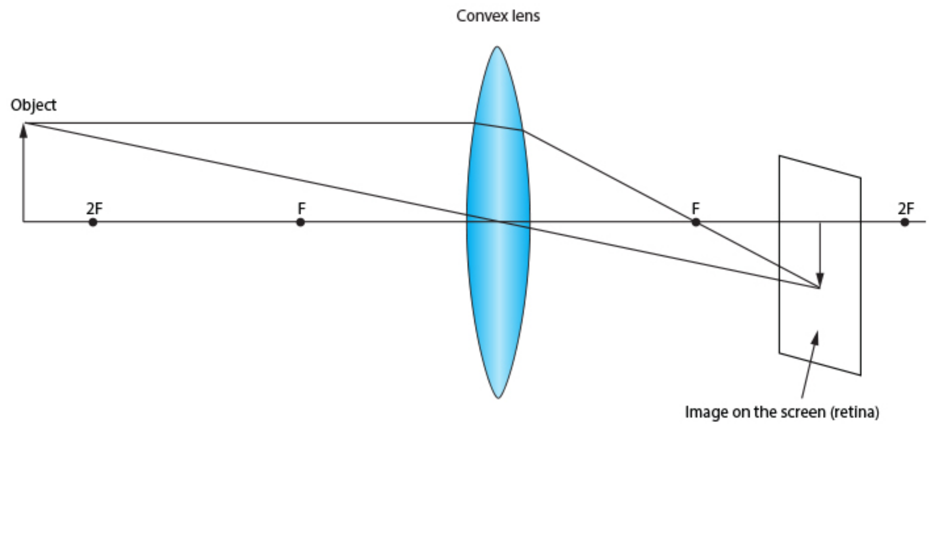

Figure 2 Shows the light rays that produce the image of the object.
(https://mammothmemory.net/physics/lenses/convex-lenses/convex-lens-uses)

The logic for the converging mirror was the same, but instead of accumulating light rays in a particular point, the rays were diffracted by the mirror according to the particular point where their imaginary lines intersected. This diffraction occurred at the focal point of the mirror, where the rays were redirected in parallel , as illustrated below.

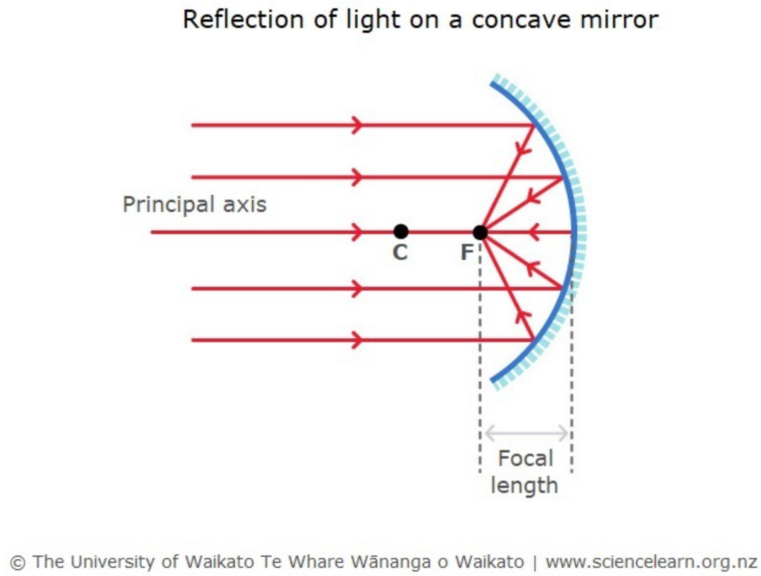

Figure 3: Shows the properties of the converging mirror(https://www.sciencelearn.org.nz/images/47-concave-,2024)

It was observed that all of the lenses and mirrors possessed a radius of curvature. This was attributed to the fact that they were slices of a larger circle, from which they were cut off. The radius of curvature was determined by calculating the radius of the big circle, using equation (3).

$$R = 2 \times f \tag{3}$$

R is the radius of curvature and f is the focal point of the lens.

Moreover, to calculate the uncertainty in large data sets, equation (4) was used.

$$\bar{x}\Delta = \frac{2\sigma}{\sqrt{N}} \tag{4}$$

The symbol $\bar{x}\Delta$ represents the average uncertainty, while σ denotes the standard deviation of the data set. The standard deviation can be calculated using equation (5), where N represents the number of repetitions in the experiment.

$$\sqrt{\frac{1}{N}\left(\sum_{i=1}^{N}(Xi^2)\right) - \bar{x}^2} \tag{5}$$

In the given equation, the symbol 'N' represents the number of repeating values (xi) in a dataset. The symbol 'x̄' represents the average of the data and can be calculated by dividing the sum of all the values in a dataset by the number of terms. Furthermore, equation (6) was employed to incorporate the uncertainty of other variables in the equations.

$$\Delta f = \left|\frac{D_i}{D_0}\right| \times \sqrt{\left(\frac{\Delta D_i}{D_i}\right)^2 + \left(\frac{\Delta D_0}{D_0}\right)^2} \tag{6}$$

Where T is the period, m is the mass of the block, and Δ on the right-hand side, terms are errors of these measurements' is the total error of the calculation.

Furthermore, The line of the best-fit method was used when the graph was plotted.

Methodology:

This experiment used three methods to investigate the properties of the convex lens and mirrors.

First method: The first method consisted of three parts; in the first part, the focal point of the convex lens was measured without the use of an optical bench. The Sun was utilized as the source of light, and the convex lens was placed in a manner that an image could be obtained on a screen. The distance between the lens and the screen was measured when the image became most clear. This distance was considered to be the focal point, as when the distance between the lens and the source of light was substituted into equation (1), the value of $\frac{1}{D_i}$ approached almost zero. As a result, the focal point was deemed to be equal to the distance between the lens and the screen.

For the second part, the optical bench was utilized, and readings of values of both D_i and D_0 were taken in ten different locations. The distance between the lens and the screen was measured when the image became clear or when the light rays constructed the smallest circle on the screen. Subsequently, all values were substituted into equation (1), and the average value for the focal point was determined. The uncertainty of the focal point was also measured by using equations (3) and (4).

For the final part of this method, a graph was plotted with $\frac{1}{D_i}$ against $\frac{1}{D_0}$, with a line of best fit. The choice of these axes was deliberate, as the intersection point of the line of best fit provided values to compute the focal point. In this case, the inverse of the focal point of the lens was calculated by reversing it.

Second part: In the optical bench, the lens and the screen were placed; when the image that was put on the light source became most clear, or when the light circle on the screen became the smallest, which was the focal point, and then, values of D_i and D_0 were taken in four different locations, and their magnification were calculated by using the equation(2).

Third part: The radius of curvature of a converging mirror was calculated using an optical bench. However, due to the non-transparency of the mirror, it was not possible to locate the focal point in the line of the optical bench. To overcome this challenge, the mirror was positioned at an angle relative to the light source, and a screen was placed parallel to the mirror. The objective was to obtain the clearest image and the smallest circle, and values of D_i and D_0 were recorded. Equation (1) was employed to determine the focal point, and equation (3) was used to calculate the radius of curvature. The method was illustrated below.

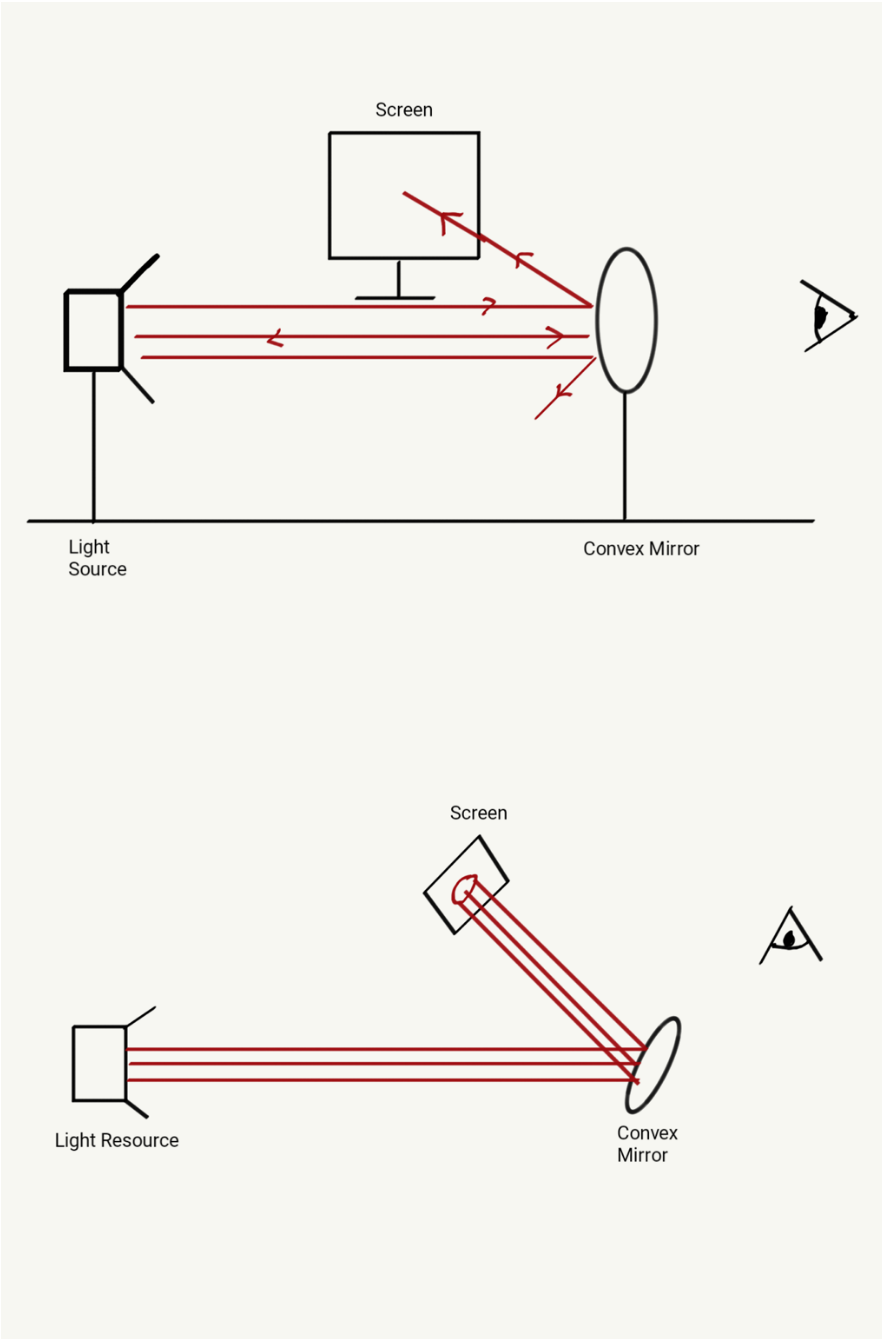

Figure 4: Illustrates the third method

Results:

For investigation one:

The focal point of the convex lens was determined, without employing an optical bench, to be $15.5 \pm 0.05\ cm$, using equation (1). The percentage error, in comparison to the literature value, was found to be 3%.

On the other hand, when the readings of D_i and D_0 were taken on the optical bench and substituted into equation (1), the average focal length was determined to be $14.4 \pm 0.3\ cm$, along with its uncertainty, using equations (4), (5), and (6). The percentage error, with respect to the literature value, was calculated to be 4%.

A graph was plotted using the reciprocal of the D_i and $D_0$0 values, with a line of best fit. The intersection point of the line of best fit was determined as $y = -0.9174x + 0.0681$. The focal point was calculated as $14.7 \pm 0.02\ cm$, along with its uncertainty, by inverting the intersection point value. The LINEST function in Excel was used to calculate the uncertainty. The percentage error, when compared to the literature value, was found to be 2%.

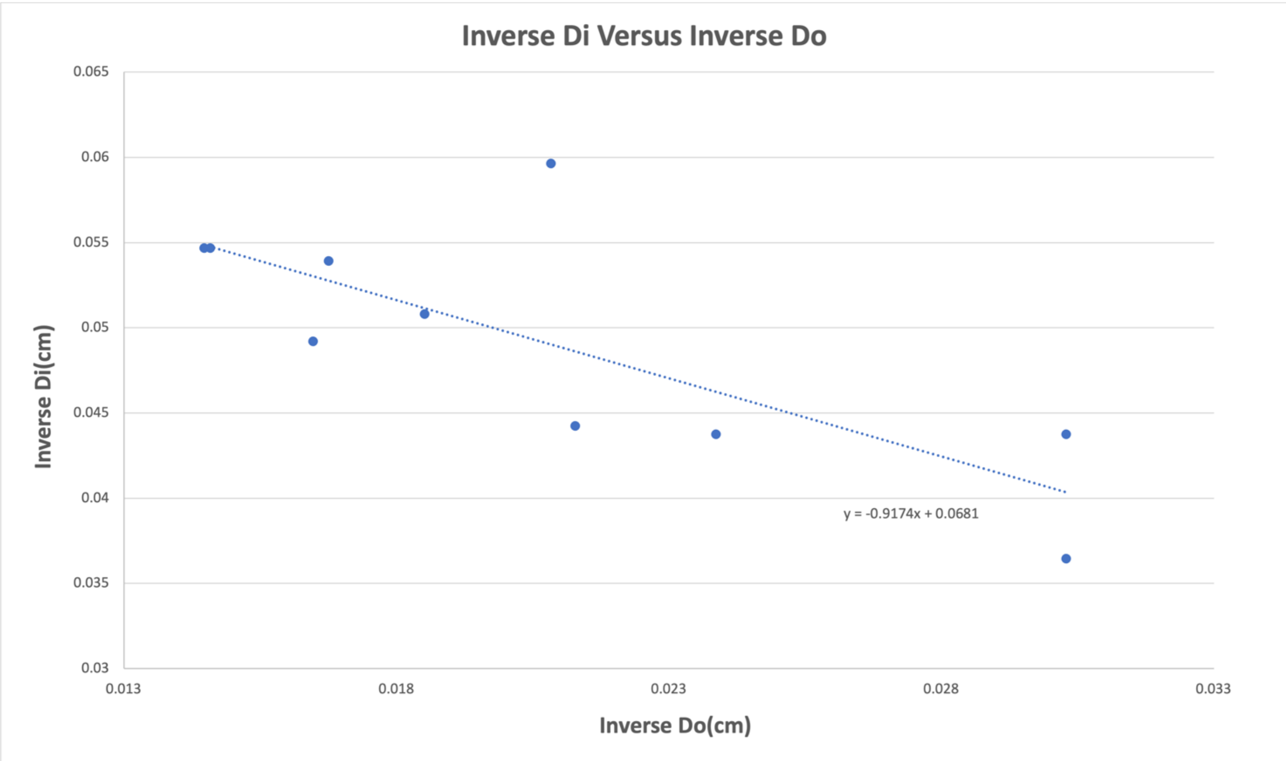

Figure 5: Shows the graph was plotted using the reciprocal D_i and D_0 values. The error bars were too small to be observable as 0.0002 in the x-axis and 0.00003 in the y-axis.

For the second investigation:

Multiple readings of D_i and D_0 values were taken in different locations to measure the magnification of the convex lens. The results for magnification were listed below, indicating the varying magnification values obtained from the experiment by using equation(2).

Magnification(cm)	$\boldsymbol{D_i}$(cm)	$\boldsymbol{D_0}$(cm)
0.35	60.5	21.0
0.5	49.5	23.0
1.35	31.5	35.5
2.7	24.3	58.2
Uncertainty (cm) = $\pm\mathbf{0.003}$	Uncertainty (cm) = ± 0.05	Uncertainty (cm) = ± 0.05

Figure 6: shows the data for the magnification of the convex lens.

For the third investigation :

The D_i and D_0 values were taken once in the experiment, the setup was explained in part of methods, then the focal point was measured in equation(1)and by substituting f into equation (3) the radius of curvature was determined as $17.40\ \pm 0.003\ cm$.

$\boldsymbol{D_i}$(cm)	$\boldsymbol{D_0}$(cm)	$f(cm)$	R(cm)
35.5	11.5	8.67	17.39
Uncertainty (cm) = $\pm$ 0.05	Uncertainty (cm) = $\pm$ 0.05	Uncertainty (cm) = $\pm$ 0.003	Uncertainty (cm) = $\pm$ 0.003

Discussion:

During the course of the experiment, various sources of error were encountered. The random source of error arose due to parallax errors resulting from readings taken from analogue instruments in all stages of the experiment. To overcome this challenge, a digital instrument with high accuracy could be employed to prevent the parallax error, thereby yielding high-calibre results and reducing uncertainties in the outcomes.

In addition, multiple readings were taken during the first and second stages of the investigation. This effectively reduced the uncertainty, as the error calculated compared to the literature value from the first method was 4% and 2%, respectively, indicating the accuracy and precision of the experiment. However, no multiple readings were taken for the third stage of investigation, and it would have been beneficial to reduce the error range. During the second stage of the investigation, four different readings were taken, and it was established that a convex lens could both reduce the size of an object and increase the image on the screen with the value range between 0.35 to 2.7.

Furthermore, it is suggested that the experiment be conducted in a darker room to enable readings to be taken more easily due to the increased focus of the human eye. The use of bigger lenses in a longer optical bench could also help reduce the error, as when the object is too small to read, the image of that object also becomes small. If the optical bench is short, there may not be enough space to observe a larger image of that object.

Conclusion:

The objective of the present study was to explore the lens equation (1) and to apply appropriate error propagation rules, as manifested in equations (4), (5), and (6). The focal point determination phase of the experiment was executed with remarkable success, as evidenced by the error values with the literature values obtained from the first method, which were found to be 3%, 4%, and 2%, respectively, thereby establishing both accuracy and precision. The optimal value for the focal point of the convex lens was determined via the first method, by identifying the intersection point of the line of best fit, yielding a value of 14.7 $\pm$ 0.02 cm. Additionally, the magnification values were calculated over a range of 0.35 to 2.7, and the radius of curvature of the converging mirror was determined using a reliable method as $17.40\ \pm 0.003\ cm$.

The utilization and validation of equation (1) for the experiment was carried out. Further inquiry was suggested to focus on the measurement of different focal points and convex lenses or mirrors. Additionally, a system could be built to magnify a small object, and the working principle of the microscope could be understood. Suggestion for decreasing the uncertainty was made in the discussion part.

Reference:

The University of Waikato Te Whare Wananga o Waikato (2022) *Convex mirror*, *Science Learning Hub*. Available at: https://www.sciencelearn.org.nz/images/48-convex-mirror (Accessed: 21 February 2024).

Convex lens uses – camera Convex lens uses - Camera. Available at: https://mammothmemory.net/physics/lenses/convex-lenses/convex-lens-uses-camera.html (Accessed: 21 February 2024).

The University of Waikato Te Whare Wananga o Waikato (2022a) *Concave Mirror*, *Science Learning Hub*. Available at: https://www.sciencelearn.org.nz/images/47-concave-mirror (Accessed: 22 February 2024).