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PHY 105N

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Lab 1: Focus on Uncertainty

Part 1

Method

For this part of the experiment, I used the following equipment: a blue laser, a large concave mirror, and a PASCO Optics Kit Mirror with a light source. A blue laser and large concave mirror was used to investigate the hypothetical focal length model; the mirror was positioned vertically on the lab table with graph paper beneath to help us get accurate measurements. During our testing of this hypothetical model, we tested whether parallel light rays converge at a single focal point, thus we directed the blue laser at the mirror parallel to the central axis at five different distances: 1cm, 2cm, 3cm, 4cm, and 5cm from the central axis.

For each distance, the reflected ray was traced and the point where it crossed the central axis was identified as the focal point. The distance from the mirror to this focal point was measured using a ruler and recorded as the focal length, f. To test the model's claim, the radius of the curvature, R, was calculated using the relationship $R = 2f$ for each trial. The measurements were taken using millimeter precision, and laser alignment was checked for each measure to ensure the rays remained parallel to the central axis; and to keep measurement uncertainty low.

Below are the sample calculations and formulas used with our data set:

Radius of Curvature: $R = 2f = 2(2.8) = 5.6$ cm

$$\text{Mean of calculated radius: } = \frac{5.6 + 7.4 + 6.8 + 6.4 + 5.0}{5} = 6.24$$

$$\text{Random Uncertainty: } \sqrt{\frac{(5.6-6.24)^2 + (7.4-6.24)^2 + (6.8-6.24)^2 + (6.4-6.24)^2 + (5.0-6.4)^2}{4}} = 0.95289$$

$$\text{Standard Deviation: } \frac{0.95289}{\sqrt{5}} = 0.42614$$

$$\text{t-score} = \frac{6.24 - 8.2}{\sqrt{(0.42614)^2 + (0.05)^2}} = 4.56803$$

Data

Table 1: Calculated Radius of Curvature at Various Distances from Central Axis

Trials	Distance of Ray(s) from the central axis (cm)	Apparent Focal Length (f) (cm)	Radius of Curvature $R = 2f$ (cm)
1	1	2.8	5.6
2	2	3.7	7.4
3	3	3.4	6.8
4	4	3.2	6.4
5	5	2.5	5.0

For blue light

In addition to the table, we also found these additional key statistical data related to Table 1:

- *Mean of Calculated Radius: 6.2*
- *Random Uncertainty: 0.9*

- *Standard Deviation: 0.4*
- *Actual Radius of Curvature (in cm): 8.2*
- *Systematic Uncertainty of Ruler (in cm): 0.05*
- *T-score = 4.6*

Conclusion

The data does not support the hypothesized model; for the first claim, parallel light did not converge at a single focal point. The apparent focal length varied from 2.5cm to 3.7cm depending on the distance of the ray from the central axis. This displays that rays farther from the center, focus at different points than the rays closer to the center. For the second claim, the calculated radius of curvature had a mean of 6.2 ± 0.9 cm (with the standard deviation of 0.4 cm). However, when the actual radius of the curvature was measured directly, we found it to be 8.2cm. The t-score comparing these values was 4.6, which indicates they're significantly different and do not agree with the uncertainty; this means the relationship $f = \frac{R}{2}$ did not hold throughout our experiment.

Some suggested refinements for future iterations of this experiment is the following: testing rays very close to the central axis to see if the model holds in a paraxial approximation, take multiple measurements at each n distance and calculate mean and standard deviation to better quantify the uncertainty, and using more precise tools or methods than the ones provided to identify where exactly the reflected rays cross the central axis.

Part II

Method

In the second part of this experiment, we investigated whether the focal length depended on the wavelength of the light used (in essence the color of the laser). To test this hypothesis, we repeated the same procedures from Part I but instead we used a red laser instead of the blue laser (found in part I). The mirror was positioned vertically with graph paper beneath for measurements purposes; the red laser was directed at the mirror parallel to the central axis at five different distances, the same set of distances as the ones found in Part I. For each distance n, the reflected ray was traced and the point where it intersected with the central axis was identified as the apparent focal point.

The distance from the mirror to this focal point was measured using a ruler and recorded as the apparent focal point, f. The radius of curvature, R, was calculated using $R = 2f$ for each trial n; measurements were taken with millimeter precision and laser alignment was checked thoroughly before each measurement to ensure for minimal uncertainty.

Below are the sample calculations and formulas used with our data set:

Radius of Curvature: $R = 2f = 2(2.4) = 4.8$ cm

Mean of calculated radius: $\dfrac{4.8 + 5.6 + 6.8 + 6.6 + 6.2}{5} = 6.0$

Random Uncertainty: $\sqrt{\dfrac{(4.8-6)^2 + (5.6-6)^2 + (6.8-6)^2 + (6.6-6)^2 + (6.2-6)^2}{4}} = 0.812404$

$$\text{Standard Deviation: } \frac{0.812404}{\sqrt{5}} = 0.36332$$

$$\text{t-score} = \frac{6.0 - 8.2}{\sqrt{(0.36322)^2 + (0.05)^2}} = 5.99876$$

Data

Table 2: Calculated Radius of Curvature at Various Distances from Central Axis

Trials	Distance from Ray(s) from Central Axis (cm)	Apparent Focal Length (f) in (cm)	Radius of Curvature $R = 2f$ in (cm)
1	1	2.4	4.8
2	2	2.8	5.6
3	3	3.4	6.8
4	4	3.3	6.6
5	5	3.1	6.2

From Red Light

In addition to the table, we also found these additional key statistical data related to Table 1:

- *Mean of Calculated Radius: 6.0*
- *Random Uncertainty: 0.8*
- *Standard Deviation: 0.4*
- *Actual Radius of Curvature (in cm): 8.2*
- *Systematic Uncertainty of Ruler (in cm): 0.05*
- *T-score = 5.9*

Conclusion

The data came to the same conclusion as of that of Part I where the red laser data showed similar patterns to the blue laser data. The apparent focal length varied from 2.4cm to 3.4 cm, depending on the ray's distance from the central axis; again indicating that parallel rays do not converge at a single point. The calculated mean radius of curvature was 6.0 ± 0.8cm (with a standard deviation of 0.4cm), compared to the actual radius of 8.2cm. Furthermore, the t-score was 5.9 confirming that these values are significantly different. Comparing the two wavelengths uncovered that the blue light gave a mean of the calculated radius of 6.2 cm while the red light gave 6.0 cm; this implies that wavelength does not significantly affect where the focal point appears for this mirror, and that the model's failure is due to geometric limitations rather than the dependence on wavelength effects.