Determination of the Focal Length of a Thin Lens Using Multiple Experimental Methods

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Abstract

The focal length of a converging thin lens was experimentally determined using six independent optical methods: object-at-infinity, thin-lens graphical analysis, Lensmaker's Formula, Bessel's Method, Laser Speckle Method, and autocollimation. The results were compared to the vendor-specified focal length of 75 mm. Among all methods, the Laser Speckle Method produced the most accurate result, yielding $f = 74.0$ mm with a percent difference of 1.35 %. Methods relying on collimation conditions consistently outperformed those requiring direct distance measurements, highlighting the impact of systematic uncertainties.

1 Introduction

Thin lenses are fundamental components in optical systems and are widely used in imaging, focusing, and beam shaping. Under the paraxial approximation, the behavior of thin lenses can be accurately described using geometrical optics [1]. A key parameter governing lens performance is the focal length, defined as the distance between the lens and the point at which collimated rays converge.

2 Theoretical Background

For a thin lens, the relationship between object distance u, image distance v, and focal length f is given by

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}. \tag{1}$$

For a symmetric bi-convex lens, the Lensmaker's Formula is

$$\frac{1}{f} = (n-1)\left(\frac{2}{R}\right), \tag{2}$$

where n is the refractive index and R is the radius of curvature of each surface.

Bessel's Method relates the focal length to the separation L between object and screen and the distance d between two sharp image positions:

$$f = \frac{L^2 - d^2}{4L}. \tag{3}$$

3 Materials

The lens under study was an N-BK7 bi-convex thin lens manufactured by Thorlabs [3]. A PASCO basic optics light source [4] and a PASCO green diode laser [5] were used as illumination sources.

4 Experimental Methods

4.1 Object-at-Infinity Method

A distant object was used to approximate collimated incoming rays. The lens was translated until a sharp image formed on a screen, and the lens-to-screen distance was recorded as the focal length.

4.2 Thin-Lens Graphical Method

Measurements of u and v were recorded for multiple object positions. A plot of $1/v$ versus $1/u$ was generated to linearize the thin-lens equation:

$$\frac{1}{v} = -\frac{1}{u} + \frac{1}{f}. \tag{4}$$

A linear regression yielded the focal length from the intercept.

4.3 Lensmaker's Method

The radius of curvature was measured using calipers, and Lensmaker's Formula was applied to calculate f.

4.4 Bessel's Method

The distance between the object and screen was fixed, and two lens positions producing sharp images were identified. The focal length was calculated using Eq. (3).

4.5 Laser Speckle Method

A diffusive surface was illuminated by a laser passing through the lens. The lens position was adjusted until the speckle pattern appeared stationary, indicating collimation.

4.6 Autocollimation

A plane mirror was placed behind the lens. The object was moved until the reflected image overlapped with the object, indicating the object lay at the focal plane.

5 Results

Table 1: Summary of focal length measurements from all methods.

Method	Focal Length (mm)	Percent Difference (%)
Object at Infinity	73.6	1.87
Thin Lens Graph	73.1	2.53
Lensmaker	69.2	7.73
Bessel	72.8	2.93
Laser Speckle	74.0	1.35
Autocollimation	73.5	2.00

6 Discussion

Methods based on achieving collimation conditions consistently yielded the most accurate results. The Laser Speckle Method minimized systematic errors associated with direct distance measurements, explaining its superior agreement with the nominal focal length.

Random uncertainties arose primarily from subjective focus determination, whereas systematic uncertainties stemmed from geometric imperfections, aberrations, and finite object distances [2]. The Lensmaker's Method exhibited the largest deviation due to sensitivity to small errors in radius-of-curvature measurements.

7 Conclusion

The focal length of a converging thin lens was determined using six experimental techniques. All methods produced results within 8 % of the nominal value, with the Laser Speckle Method providing the highest accuracy. These findings demonstrate the effectiveness of collimation-based techniques for minimizing systematic uncertainty in focal-length measurements.

References

[1] J. Peatross and M. Ware, *Physics of Light and Optics*, Brigham Young University (2015).

[2] E. Hecht, *Optics*, 5th ed., Pearson Education (2017).

[3] Thorlabs, Inc., *LB1901-B Bi-Convex Lens Datasheet*.

[4] PASCO Scientific, *OS-8470 Basic Optics Light Source*.

[5] PASCO Scientific, *OS-8458B Green Diode Laser*.