Thin Lens Experiment

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16 November 2021

1 Introduction

In this experiment, the focal length of a converging lens will be measured using two different methods, namely the thin lens formula and Bessel's method. Also with that particular converging lens, the virtual object method will be used to measure the focal length of a diverging lens.

2 Theory

The main idea behind the formula for the thin lens equation is that the optical path length for all the light rays emitted from a point should be the same. And while deriving the formulas approximations being made, one is the incident angle and the incident and reflection angles are small enough to assume that

$$sin(\alpha) \approx \alpha \tag{1}$$

The second approximation is that the distance between the two spherical surfaces of the both thin lens and diverging lens assumed to be negligibly small. The exact derivation can be found from any classical textbook on Optics[1]. The following equation is known as the thin lens equation;

$$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f} \tag{2}$$

Where s_0 is the distance from the object to the lens, s_i is the image distance to the lens and f is the focal length of the lens.

Dealing with an optical system with many elements such as different indices medium or refraction through a spherical surface points out the necessity to represent each of these operations as linear transformations of the 2x1 vector, whose entries represents the angle of the light with the optical axis and the position, where the light emerges. Thereby it is easy to derive the basic build blocks of an optical system namely; the translation matrix, reflection matrix, and refraction matrix. Keeping this into consideration finding the focal point of a matrix essentially reduces to solving the following quadratic equation.

$$d = \sqrt{D(d-4f)} \iff f = \frac{D^2 - d^2}{4D} \tag{3}$$

Finding the focal length of the diverging lens is not possible directly but using a known focal length converging lens under the condition $\mid \frac{1}{f_{diverging}} \mid < \frac{1}{f_{converging}}$ if this is not satisfied then the light rays from the source will not converge. The following formula can be derived when the condition is satisfied, thus it is possible to obtain the focal length of the diverging lens.

$$f_{diverging} = \frac{s_i'(s_i - d)}{s_i - (s_i' + d)} \tag{4}$$

Where s_i is the first screen position to the converging lens, s_i' is the second screen position to converging lens and d is the distance between two lenses.

3 Results

All of the following results are in centimeters. For the calculation of the error propagation an online error propagation calculator is used [2]. The manufacturer's uncertainty of the lenses is given as ± 0.05 cm and all of the measurements other than focal length have uncertainty ± 0.2 cm. The focal length of the converging and diverging lenses are given as +7.5 cm and -15.0 cm beforehand.

Result Table For Part A

Object Distance, s_o	Image Distance, s_i	Focal Length, f_m
9.6	33.7	7.471 ±0.165
17.15	12.6	7.326 ±0.151
28.7	10.0	7.416 ±0.161

Result Table For Part B

d	D	Focal Length, f_m
19.2	40.0	7.6 ±0.0801
18.2	39	7.62 ±0.0831
13.2	34.9	7.47 ±0.0724

Result Table For Part C

s_i	s'$_i$	d	Focal Length, f_m
24.4	18.2	16	-15.6 ±0.5
21.7	20.3	13	-15.2 ±0.477
18.4	19.4	10.2	-14.2 ±0.439

4 Discussion

When the derivations in the theory section are made the paraxial approximation is used. But the deficiency that the approximations make can not be seen from the result because the error of the ruler and the sliding mechanism that is being used to adjust the screen and take the measurement is too high compared to the approximations. Overall the data presented in the results section is in agreement with the focal length of the lenses with the manufacturer's error. Also except for the first part, the measurements bounds the given focal length below and above.

Considering the uncertainty in the measurements, the experiments confirm the theory, but in order to see the effects of the paraxial approximation, the measurement should be made by the devices that have a significantly low error percentage.

5 References

1- Frank L Pedrotti, Leno M Pedrotti, Leno S Pedrotti - Introduction to Optics (2006)
2- https://www.eoas.ubc.ca/courses/eosc252/error-propagation-calculator-fj.htm