Geometrical Optics

PHYS 2202: Wave Motion and Optics

Lab Section A2

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0. Contents

1. Introduction

1.1 Objectives

This experiment was designed to explore a variety of different techniques that can be used to measure the focal length of a spherical lens. In the following pages we describe how theoretical equations were manipulated to make focal length depend on different measurable quantities, the different methods created for measuring those quantities, and how well those methods compare with each other.

In exploring the following techniques, we also gained a deeper intuitive understanding of the geometrical optics principles underlying the techniques. Namely, the laws of reflection, refraction, and magnification.

1.2 Thin Lens Equation

First, we use the "thin lens" equation:

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

which tells us the relation between the focal length of a lens f, the distance of the object from the lens along the optical axis s_o, and the distance of the image along the optical axis s_i. Note that this equation assumes all rays are paraxial, and that the lens is spherical and of negligible thickness. Importantly, for an object on the optical axis, s_i is where the image will be in focus.

Then perhaps the most straightforward approach to measure the focal length is to place an object along the optical axis and measure where the image is in focus. In order to make use of these quantities, we rearrange the thin lens equation to find:

$$f = \frac{s_o s_i}{s_o + s_i} \tag{1.1}$$

Alternatively, using many trials, we may plot $\frac{1}{s_o}$ against $\frac{1}{s_i}$ and find the focal length at the y-intercept, that is, as $\frac{1}{s_i} \to 0$. This concept is exploited further in the next section.

1.2.1 Limits at Infinity

There is yet more we can do. Note that in the thin lens equation, if $s_o \to \infty$, then that respective term goes to zero, and we obtain an extremely simple relation for f. Namely,

$$\begin{aligned} \frac{1}{f} &= \lim_{s_o \to \infty} \left(\frac{1}{s_o} + \frac{1}{s_i} \right) \\ &= \frac{1}{s_i}, \end{aligned}$$

or equivalently,

$$f = s_i \tag{1.2}$$

A similar process with $s_i \to \infty$ gives us

$$f = s_o \tag{1.3}$$

Finally, we exploit the concept of an "object at infinity" by noting that it is equivalently an object emanating parallel rays of light. Thus we can approximate an object at infinity by a distant object, and simulate an image at infinity by a mirror.

1.2.2 Using Magnification

For this method we use what we know about magnification under the previously stated approximations, namely,

$$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o},$$

which we combine with the thin lens equation to find

$$\frac{1}{M} = -\frac{s_o}{f} + 1 \tag{1.4}$$

So may plot $\frac{1}{M}$ against s_o to find f as the slope.

1.3 Lensmaker Equation

The lensmaker equation gives us a way to find the focal point of a double lens based on its geomtry. In particular,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

$$\Downarrow$$

$$f = \frac{R_1 R_2}{(R_2 - R_1)(n-1)} \tag{1.5}$$

where R_1, R_2 are the radii of curvature of each side of the lens, and n is the refractive index of the lens' material. Using a spherometer, these radii are found by

$$R = \frac{r^2 + d^2}{2r} \tag{1.6}$$

where r is the spherometer reading, and d is the distance from the leg of the spherometer to the screw. So by simply taking some readings of the lens using the spherometer, we are able to find its focal length.

2. Experimental setup

Procedure.

Apparatus. The instruments used are as follows:

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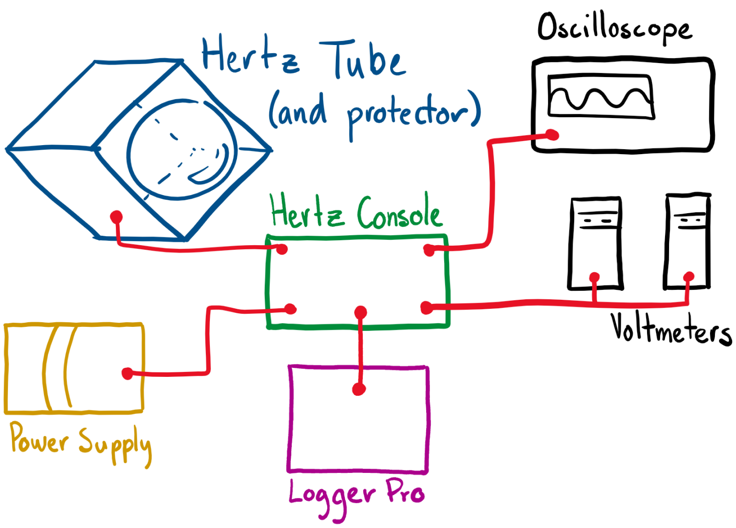

Figure 2.1: Schematic diagram of the experiment.

3. Observations

All measurements taken with ruler, metre stick, or spherometer. Any uncertainties not listed are equal to the reading uncertainty of the metre stick, that is, ± 0.5 [mm].

3.1 Object at Infinity

Trial	Image Distance [mm] $\left(\pm\frac{\sqrt{2}}{2}\right)$
1	190
2	190
3	195
4	190
5	190

Table 3.1: Measurements taken of image distance, as in **??**

3.2 Mirror Method

Trial	Object Distance [mm]	Lens Distance [mm]
1	150	343
2	170	366
3	200	395
4	250	445
5	300	494

Table 3.2: Measurements taken of object and lens when image in focus

3.3 Lensmaker Equation

LtS Distance [mm] $\left(\pm\frac{\sqrt{2}}{2}\right)$
22.5

Table 3.3: Leg-to-screw distance of the spherometer

Trial	Front Reading [mm] (±0.025)	Back Reading [mm] (±0.025)
1	1.34	1.41
2	1.275	1.3
3	1.28	1.285

Table 3.4: Spherometer readings of front and back lenses, as in **??**

3.4 Thin Lens Equation

Trial	Object Distance [mm]	Lens Distance [mm]	Screen Distance [mm]
1	150	550	940
2	150	500	952
3	150	600	957.5
4	150	650	983
5	150	520	944
6	150	540	942
7	150	560	948
8	150	580	950
9	150	480	966.5
10	150	460	998

Table 3.5: Measurements taken of object and lens when image in focus

3.5 Magnification and Thin Lens: Vertex Pointers

Trial	Obj. Dist. [mm]	V_1 [mm]	V_2 [mm]	V_3 [mm]	V_4 [mm]	Img. Height [mm] $\left(\pm\frac{\sqrt{2}}{2}\right)$
1	150	221	516	685.5	877.5	-15
2	150	221	496.5	665	869	-16
3	150	221	477	645	868.5	-17.5
4	150	221	456.5	624.5	861	-19
5	150	221	437	645	867	-21
6	150	221	417	584.5	866	-25
7	150	221	396.5	565	887.5	-27.5
8	150	221	375.5	444.5	925.5	-33
9	150	221	545	712	894	-14

Table 3.6: Measurements taken of object, lens, and image height when image in focus

4. Data analysis

5. Results

6. Discussion