Lenses

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Performed: November 12, 2014

Due: November 19, 2014

Objective:

To observe the refraction of light through lenses and study the results of placing multiple lenses together.

Description:

There was an optical bench on the table, at one end of which a laser was placed. The lens holders and the screen could be moved along the optical bench in order to adjust the position of the lenses. The optical bench had a built in meter ruler to measure distances between lens-holders.

4.1 Convex Lens

- The image was upright for object distances less than the focal length for all three lenses. The lens with the smallest focal length displayed the greatest change in image size i.e. strongest magnification.

- The image was inverted for object distances greater than the focal length for all three lenses.

- Convex lenses resulted in a magnified image, and the image gets larger as the lens is moved closer to the object

- The lens with the smallest focal length had the largest magnification so defining strength as $1/f$ makes sense

4.2 Concave Lens

- The concave lenses give upright images for all three lenses.

- The images are typically diminished (never magnified), and images get smaller as object distance increases.

5 Qualitative Analysis with Laser Beams

- Yes, the deflection of the beam is in the expected direction.

- With the convex lenses, expected deflection is in the direction toward the focal axis, which is consistent with our observations.

- With the concave lenses, the deflection is in the direction away from the focal axis, as is expected.

- Deflection is directl proportional to the strength of the lens.

6.1 Focal lengths of convex lenses

Expected focal length (in mm)	Experimental focal length (in mm)
252	212
127	119
48	41

As the focal length decreases (i.e. the strength increases) the uncertainty in the focal length also decreases. This is because the changes in sharpness of the image are greater for a lens of greater strength, the point of focus is therefore significantly more noticeable.

6.2 Focal lengths of concave lenses

Expected focal length (in mm)	Experimental focal length (in mm)
-22	12

7 Verifying the lens formula, using the 48 mm lens

Object Distance ($\pm$0.2 cm)	Image Distance ($\pm$0.2 cm)	Focal Length ($\pm$2.8 mm)
19.40	6.00	45.8
40.15	5.00	44.5
9.10	9.30	46.0
30.00	5.25	44.6
64.70	4.90	45.5

The results obtained from the thin lens formula are very close to the experimental value, and within the range of uncertainty assuming an uncertainty of 2mm in the measurements of object and image distance.

8 Using two lenses placed close together

Focal lengths of the individual lenses were: 127mm and 252mm.

The resultant focal length can be found using the equation:

$$\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{f}=\frac{1}{127}+\frac{1}{252}=0.0118 \quad \rightarrow \quad f=84.44$$

Object Distance (±0.2 cm)	**Image Distance (±0.2 cm)**	**Focal Length (±2.8 mm)**
12.90	18.90	76.4
27.70	12.50	86.1
38.40	11.20	86.7
51.00	10.60	87.7
63.40	10.00	86.4

The mean of the experimental values of focal length is 84.66mm which is within 0.22mm of the theoretical value. With the uncertainty propagated from our measurements, we see that most of the values for focal length calculated experimentally are within the range of uncertainty.

9 Qualitative analysis: Two Separate Lenses

Placing the 127mm lens and the 252mm lens as suggested in the manual, we moved the screen so the image was focused. Interchanging the two lenses gave a blurry image as expected, this is because the separated lenses act like a thick lens where the image created by one acts as the object for the other. Their positions are not interchangeable.

10 Quantitative analysis: Two Separate Lenses

Object 1	**Object 2**	**Distance (in cm)**
Bulb	48 mm lens	8.0
48 mm lens	127 mm lens	34.0
127 mm lens	image	38.4

Using the lens equation, we get:

$$\frac{1}{i'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{48} - \frac{1}{80} \cong 0.0083 \rightarrow i' = 120\text{mm}$$

Since this image is formed on the same side of the 48mm lens as the 127mm lens, the source distance for the second lens is: (340-120)mm = 220mm. using this as the object length for the second lens, we get:

$$\frac{1}{i} = \frac{1}{f} + \frac{1}{s} = \frac{1}{127} + \frac{1}{220} \cong 0.0033 \rightarrow i = \ 300\text{mm}$$

Original Experiment

For the original experiment we placed a green filter in front of the laser pointer

New focal point was: 5.7cm

Object distance (cm)	Image distance (cm)	Focal length (cm)
11.2	8.5	4.80
25.5	5.9	4.79
41.7	5.4	4.78
52.4	5.25	4.77

From here we can see that the focal length is 47.85mm, standard deviation = 0.13cm, uncertainty in the mean = 0.065cm

12 Questions

- A green laser would give different results than the red laser because the index of refraction (and therefore focal length) depends on the frequency of light. This means that for the same lens, different colors will have focused images at different locations so a white object would focus as a somewhat blurred colored image.

- If two lenses have the same dimensions but different indexes of refraction, their focal lengths will be different. This is especially evident if we take rectangular blocks of different materials – say water and glass – and notice that refraction through the two is not identical. A similar observation can be made with an empty glass and a glass full of water. This shows us that refraction depends on the material even for the same shape.
- Equation 1 gives us that, for the first lens:

$$\frac{1}{f_1} = \frac{1}{s} + \frac{1}{i'}$$

And for the second lens:

$$\frac{1}{f_2} = -\frac{1}{i'} + \frac{1}{i}$$

On adding these two, we get that:

$$\frac{1}{f_1} + \frac{1}{f_2} \quad = \quad \frac{1}{s} + \frac{1}{i'} - \frac{1}{i'} + \frac{1}{i} \quad = \quad \frac{1}{s} + \frac{1}{i} \quad = \quad \frac{1}{f}$$

Which is what equation 4 gives us