Abstract:

The goals of this lab were to determine properties of a thin diverging lens such as focal length, radii of curvature and the index of refraction. Our values for Lens B were as follows:

<u>Radii of Curvature</u>

R = 7.9 ± 0.2 cm

<u>Focal Length</u>

f = -13.8 ± 0.4 cm

<u>Index of Refraction</u>

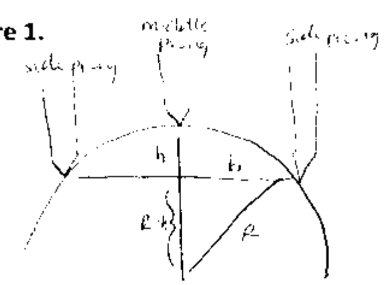
n=1.57 ± 0.02

Introduction:

In the first part of the experiment, we were asked to find the radius of curvature R. The radius of curvature is the radius of a sphere that the lens would form if its curvature was made into a sphere. Thus, a flatter lens has a larger radius of curvature. The Lensmaker's Formula contains R_1 and R_2 because lenses have two sides so there are two radii of curvature. In this experiment, the divergent lens was a plano-concave lens, which means one side was curved, and the other side was flat. Thus, we only needed to determine R_1 for the curved side and we know that R_2 for the flat side, has a radius of curvature of infinity.

To find R_1, we used a spherometer to measure the height of the curve of the lens and then used trigonometry to then determine the radius of curvature of our lens. We first had to find the "zero" position of the spherometer and make our measurements relative to this position. After we had a "zero" position, we were able to place the spherometer on the lens and take a measurement of h, the height difference between the side and middle prongs of the spherometer. We also measured the distance between one of the prongs of the spherometer and the middle prong to determine the distance b. Once we had these three measurements, we were able to use the equation derived using the Pythagoras Theorem in Appendix I of the lab to determine R:

Figure 1.



$$R^2 = (R-h)^2 + b^2$$

$$R^2 = R^2 - 2Rh + h^2 + b^2$$

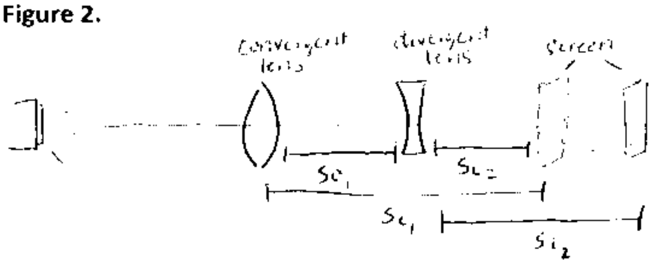
$$R = \frac{h^2}{2h} + \frac{h}{2}$$

In the second part of the experiment, we were asked to find the focal length f of our lens, lens B. The focal length f, is the second of the three characteristics of a thin divergent lens that we investigated in this lab. The focal length is the minimum distance required to focus an object an infinite distance away. It actually depends on the radii of curvature and the index of refraction via the Lensmaker's Formula:

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$ where for a plano-concave lens, $R_1 = \infty$

To find the focal length, we used our convergent lens from last week to focus an image of the crosshairs on the lamp on a screen. Next, we placed divergent lens B between the convergent lens and the image and measured the distance from the divergent lens to the screen. Then we moved the screen back until the image came back into focus and measured the distance between the divergent lens and the screen.

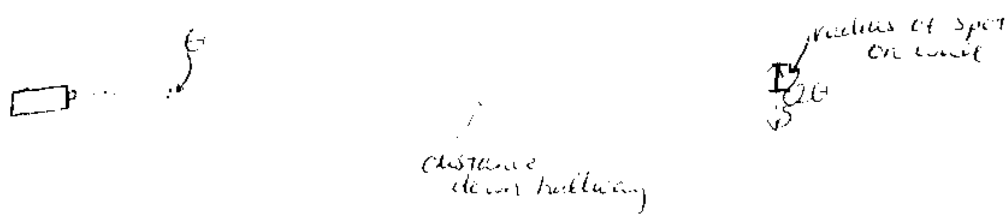
Figure 2.



In the third part of the lab, we were asked to calculate the third property of a thin converging lens, the index of refraction *n*, using the Lensmaker's Formula. The index of refraction is different for all types of material. It is found by the equation $n = \frac{c}{v}$ where c is the speed of light in a vacuum and v is the speed of light through the material.

In the fourth part of the experiment, we were asked to aim a laser beam down a long hallway onto a distant wall and measure the radius of the maximum spot size that can be discerned to determine whether or not the laser beam diverges.

Figure 3.



In the fifth part of the lab, we were asked to form a Galilean telescope with our lenses to form a laser beam expander/reducer. To determine if we did this correctly, we were asked to measure the beam diameter before it entered the lenses, and at several distance beyond the lenses. The main idea for a Galilean telescope is that the distance separating the lenses is equal to the sum of their focal lengths.

Analysis and Discussion:

In the first part of the experiment, we found *h* using a spherometer. The value we found for *h* was:

$$h_1 = 1.43 \pm 0.01 \text{ mm}$$

There is no h_2 because the lens was a plano-concave lens so one side was flat. The uncertainty in the height *h* was found using: $\sigma_h = \sqrt{(\sigma_1)^2 + (\sigma_0)^2}$. Inserting my values, $\sigma_h = 0.01$ mm.

We then measured *b* to be 1.50 ± 0.01 cm.

Lastly, we calculated the radius of curvature using the *h* and *b* values we found and their uncertainties. We used the equation derived above to determine *R* and then we used the following equation from Appendix II of last week's lab to determine the uncertainty:

$$\sigma_R = \sqrt{\left(-\frac{b^2}{h^2} + \frac{1}{2}\right)^2 {\sigma_h}^2 + \left(\frac{b}{h}\right)^2 {\sigma_b}^2}$$

The value of the radius of curvature that we found, including the uncertainty calculated using the above equation, was:

$$R_1 = 7.9 \pm 0.2 \text{ cm}$$

For part two of the experiment, we determined the focal length *f* of the divergent lens using the equation:

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

We found the *f* values for four different lens-screen separations and averaged them. To find the uncertainty in *f*, we used the following uncertainty equation from Appendix II of last week's lab:

$$\sigma_{f_n} = \sqrt{\left(\frac{\frac{1}{{s_o}^2}}{\left(\frac{1}{s_o} + \frac{1}{s_i}\right)^2}\right)^2 {\sigma_{s_o}}^2 + \left(\frac{\frac{1}{{s_i}^2}}{\left(\frac{1}{s_o} + \frac{1}{s_i}\right)^2}\right)^2 {\sigma_{s_i}}^2}$$

This equation only takes into account one trial, f_n, the uncertainty for the average focal length was found by using the following equation:

$\sigma_f = \frac{\sigma_{f_n}}{\sqrt{n}}$ where in our case, n = 3.

Using the thin lens equation from above, and the uncertainty equations just discussed, our value for the focal length came out to be:

$$f = 13.8 \pm 0.4 \text{ cm}$$

Q1. The focal length found above, f =-13.8 ± 0.4 cm, is compared to the focal length found by using the Lensmaker's Formula and assuming n=1.50, f = -15.8 ± 0.4. The uncertainty was calculated using the following equation: $\sigma_f = \sqrt{\left(\frac{1}{n-1}\right)^2 \sigma_R{}^2}$. There is no term for the σ_n because we assume no uncertainty in the index of refraction for this calculation. By $|\Delta| \leq \delta\Delta$, these values for the focal length are not compatible: $|2| \leq 0.8$. I think we were not harsh enough with our uncertainty values in the measurements again. If we did a better job estimating our errors, we may have closer values.

In the third part of this experiment, we were asked to find the index of refraction n including its uncertainty and then compare it to last week's lab value of n. We rearranged the Lensmaker's Formula to find the index of refraction:

$$n = \frac{1}{f\left(\frac{1}{R_1} - \frac{1}{R_2}\right)} + 1$$, where for a plano-concave lens, $R_1 = \infty$

To get our uncertainty, we used the following equation:

$$\sigma_n = \sqrt{\left(-\frac{\frac{1}{f^2}}{\left(\frac{1}{R_1}\right)}\right)^2 \sigma_f{}^2 + \left(-\frac{\left(\frac{1}{f}\right)\left(-\frac{1}{R_1{}^2}\right)}{\left(\frac{1}{R_1}\right)^2}\right)^2 \sigma_R{}^2}$$

Using these equations to solve for n and its uncertainty, we achieved the result:

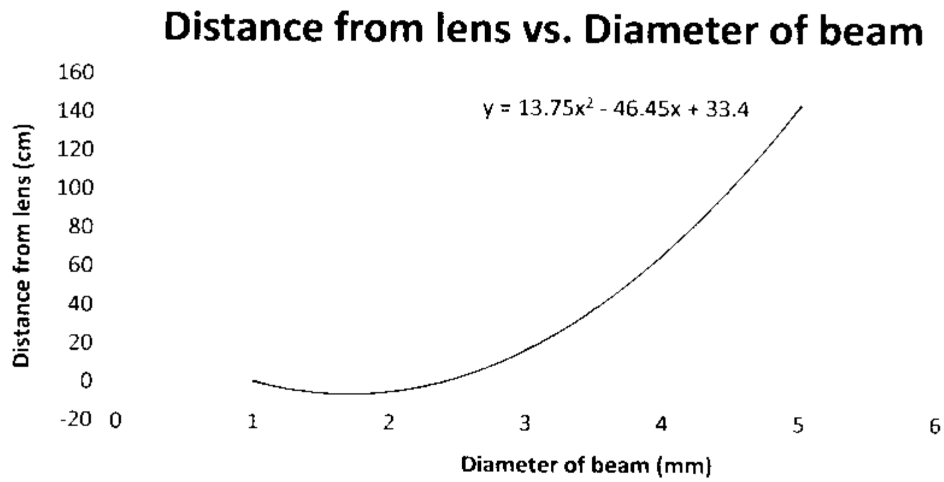
n=1.57 ± 0.02

The textbook gives a value of n = 1.50 for glass. Assuming our lens was made of pure glass, we are 3.5 standard deviations away from the accepted value. It is possible that our lens was not made of pure glass like we assumed. Also, if there were chips or scratches in addition to impurities in the glass, that would slow down the speed of light going through the glass and result in a higher n value.

In part four of the experiment, we were asked to determine whether or not the laser beam diverges. We determined that it does indeed diverge.

Q2. The spot was not of uniform brightness. There was a clear bright spot in the middle, then a dimmer circle of light around the inner bright spot. To determine2θ, we found the length of the hallway and the diameter of the beam. From this, we could use trigonometry to determine θ and thus 2θ. We determined 2θ = 7.47 x 10^{-4} rad = 0.0428°

In the fifth and final part of the experiment, we were asked to create a Galilean telescope with our lens and to measure the beam diameter before and at several distances beyond the lenses.



Q3. Even at a small distance, it is evident that the beam is diverging. The divergence angle is equal to θ which is what we determined in the fourth part of the experiment. The divergence angle therefore equals $\theta = 3.74 \times 10^{4}$ rad = 0.0214°

Q4. The magnification of the beam can be found by calculating $M = -\frac{f_1}{f_2}$. For our beam,

$$M = -\frac{15.9}{-13.8} = 1.15$$

This is consistent with the two lens equation when $d = f_1 + f_2$.

Conclusion:

An index of refraction of n=1.57 ± 0.02 calculated using the Lensmaker's Formula and a focal length of f = -13.8 ± 0.4 cm and radius of curvature R = 7.9 ± 0.2 cm is near what I expected to achieve, assuming the lens was made of glass. All values seem to fit with thin lens theory.

Throughout this lab I thought we were being very generous in our error analysis, but for the final calculation of the index of refraction, we still ended up with a pretty small uncertainty. We probably could have given ourselves more room for error in some of the measurements.

Sources:

1. Class text, Optics 4th Ed. Eugene Hecht