# Department of Physics / Umeå University Double column Template

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**Abstract**
The thin lens equation can predict how lenses in an optical system refract light. In this exercise, we investigated how well our theoretical predictions coincided with our experimental findings. *What was done?* Using the thin lens equation, we first derived the distance to the image plane for an object positioned in front of a convex and concave lens and thereafter experimentally measured the the distances. *How was it done?* We found that the experiments agreed with the theoretical predictions, with a discrepancy of only 1.0 $\pm$ 0.2 mm. *What was found?* We then built and verified the performance of both a Kepler and a Galilean telescope. We found that theory and experiment coincided with a discrepancy of 3.0 $\pm$ 0.3 mm. However, we observed a significant amount of aberrations, which we suggest is related to the spherical lenses used in the setup. The findings in this exercise suggest that the thin lens equation can accurately predict how lenses should be positioned for imaging purposes, but that it does not take into account the degree of aberrations. *What is the significance of the findings?.*

**Keywords**
Optics — Interference — Diffraction

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## Contents



## 1. Introduction

The thin lens equation provides the quantitative relationship between the object distance, the focal length, and the image distance. We investigated how well this equation could predict the refraction of light in optical lenses. *Identifies the scientific concept which forms the learning context for the lab* The thin lens equation, which is also denoted the Gaussian lens formula, was derived by Edmund Halley in 1693 under the assumption that the thickness of the lens is ignored and that the paraxial assumption is used [1]. This simplifies ray tracing calculations but give rise to errors if the rays are focused by the outer part of a lens [2]. *Background of the scientific concept* Therefore, we assumed to have some discrepancy between the theoretical and experimental values.

Our main objective was to theoretically calculate the relation between the position of the object and image plane for a number of lenses and a train of lenses, and thereafter verify the calculations using a set of real lenses. The calculations were also compared to manually drawn ray-tracing diagrams using pen and paper. *Paragraph that identifies the objectives in the lab*

## 2. Methods

### 2.1 Theory

The thin lens equation can be derived from the thick lens equation [3]. By denoting $s$ and $s'$ as the object and image distances, respectively, and $s_{i1}$ as the image distance due to refraction in the first surface a relation can be expressed as,

$$\frac{n_m}{s} + \frac{n_m}{s'} = (n_1 - n_m)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) + \frac{n_1 d}{(s_{i1} - d)s'}, \quad (1)$$

where $n_m$ and $n_1$ are the refraction index for the glass and air, respectively, $R_1$ and $R_2$ are radii of curvature of the surfaces, and $d$ is the thickness of the lens. If the lens thickness is $d << s_{i1}$, Eq. (1) can be rewritten and simplified as,

$$\frac{1}{s} + \frac{1}{s'} = \left(\frac{n_1}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right), \quad (2)$$

which is known as the lens maker's equation or thin lens equation. For a thin lens, the focal length of the object, $f_0$, equals the focal length of the image $f_i$, therefore, we can define,

$$\frac{1}{f_0} = \frac{1}{f_i} = \frac{1}{f}. \tag{3}$$

The definition in Eq. (3) together with Eq. (2), yields the fundamental and practical thin lens equation,

$$\frac{1}{f} = \left(\frac{n_1}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{1}{s_s} + \frac{1}{s'}. \tag{4}$$

### 2.2 Experimental procedure

We used a small light emitting diode as an object and imaged it on a white 10x5 $cm^2$ screen, using different lenses. The lenses were made of glass and either biconvex or biconcave with a diameter of 7.0 cm. All components; the diode, lenses, and the screen were mounted in sliding holders, which could be moved and locked on a metal rail for accurate positioning. An illustration of the setup is shown in Figure 1.

To measure the positions of our objects we used a stainless steel ruler and assumed a $\pm$ 1.0 mm accuracy in each measurement. This assumed accuracy was further used to calculated the error by using Gauss error propagation formula [4]. *A description of the method used for statistical analysis*

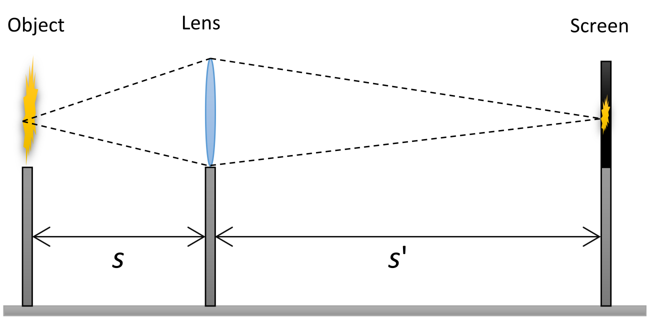


**Figure 1.** Schematic of the setup used to mount the optical components (light emitting diode, lens, and screen) and measure how light was refracted by the lenses. A 5 mm light emitting diode was used as an object and the the white screen was moved until a sharp image was seen. The distances were measured using a regular steel ruler.

## 3. Results

### 3.1 Verification of the thin lens equation

Our experimental findings are in good agreement with theoretical calculations. *Start with a sentence that highlights the findings for each result, support this with facts* We first verified the thin lens equation of a concave and convex lens of 15.0 cm and -15.0 cm focal length, respectively. For an object distance of 25.0 cm we derived an image distance of 37.5 cm and 9.4 cm. The experimentally measured image distances, the distance from the lens to the screen, were 37.1 $\pm$ 0.2 cm and 9.1 $\pm$ 0.2 cm, respectively.

Next, we calculated how to position two positive lenses of 5.0 cm and 25.0 cm focal length in order to image distant objects, i.e., more than 50 m away. This type of setup resembles a Kepler telescope. We found that the telescope provided almost five time magnification when looking at distant objects but that the image was significantly distorted. We therefore carefully realigned the lenses such that the optical axis of the two lenses were at the same height, which reduced the amount of aberrations. *The text should tell a story*

### 3.2 Chromatic aberrations

Chromatic aberrations are a result of dispersion, that is the variation of the index of refraction of a medium with wavelength. The following text is not explaining this but is just placed here to fill the page. Figure 2 is also just a dummy figure and is placed there to show how a figure can be neatly positioned across two columns.

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## 4. Discussion and Conclusion

The thin lens equation is an approximate equation that can predict the distance from a lens to an image, given the distance

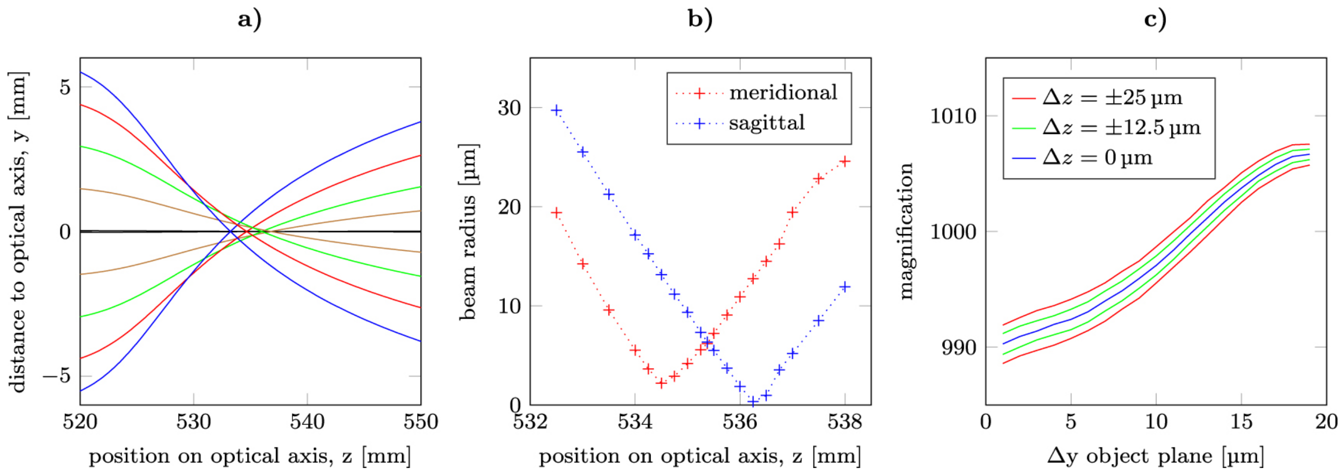


**Figure 2.** Example of a double column figure with three subplots.

from an object. Using this equation, we investigated and compared the accuracy between theoretical prediction with experimental data. *One to three sentences to introduce what was done*

The theoretical and experimental results for the concave and convex lenses agreed well, however, the theoretical values were slightly overestimated. We suggest that this overestimation is due to the rather large-sized lenses used in the exercise. Rays refracted by a large-sized low-quality lens will produce an elongated focus along the optical axis since these rays are focused closer to the lens than those refracted by the central part of the lens. Thus, it was difficult to find the exact focal position when positioning the screen, and the measured distance therefore included errors. *Analyzing results 1*

For the telescopes we experienced that the alignment procedure was very important. In the first setup, we positioned the lenses according to the distances calculated with the thin lens equation. Thus, when viewing distant objects, the images were significantly distorted. We corrected this, however, by carefully centering their optical axis when realigning, and managed to get a decent agreement between theory and experiment. *Analyzing results 2*

Since we used a regular steel ruler with mm resolution to measure and estimate the distances, our data had errors. To minimize these errors all members in the group made individual measurements each time and we used the average values. *What errors did you have?*

Since the thin lens equation is derived under the assumption that the lens has no thickness, and we used thick lenses in the exercise, we initially assumed that this would give a slight overestimated distance, Eq. (1) and (4). Indeed, all experimentally measured values agreed with this hypothesis. Despite this, we are satisfied with the outcome of the exercise since it still proved that the simple thin lens equation, with good accuracy can predict the image position, given the lens focal length and the distance from the object to the lens. *Prediction based upon analyzing the theory*

In conclusion, we verified the validity of the thin lens equation using different optical systems, and found that our experimentally measured distances coincided well with the theoretical predictions. *Concluding the findings in the laboratory exercise*

## References

[1] Steinhaus, H., Mathematical Snapshots, 3rd Edition. New York: Dover, pp. 93-94, (1999)

[2] Greivenkamp, J. E., Field Guide to Geometrical Optics, SPIE Press, Bellingham, WA, (2004)

[3] Pedrotti, F.L. and Pedrotti, L.S., Introduction to Optics, 3rd Edition, Addison-Wesley, (2006)

[4] UC Davis ChemWiki, Propagation of Error, Available at: https://chem.libretexts.org/Textbook_Maps/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Quantifying_Nature/Significant_Digits/Propagation_of_Error, (Accessed: 10th March 2016).

## Appendix

This sample report can hopefully be of help when you write *your* report. Remember that writing is a craft and requires a lot of practice. Use the information found in *Att skriva och presentera rapporter*, which gives you detailed advice of each section of a report. If you are interested in improving your writing skills, we recommend you to read the book by Joshua Schimel - *Writing Science: How to Write Papers That Get Cited and Proposals That Get Funded.* 2011. Oxford University Press. Another great book that we recommend is the book by Joseph M. Williams -*Style - Lessons in Clarity and Grace.*

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