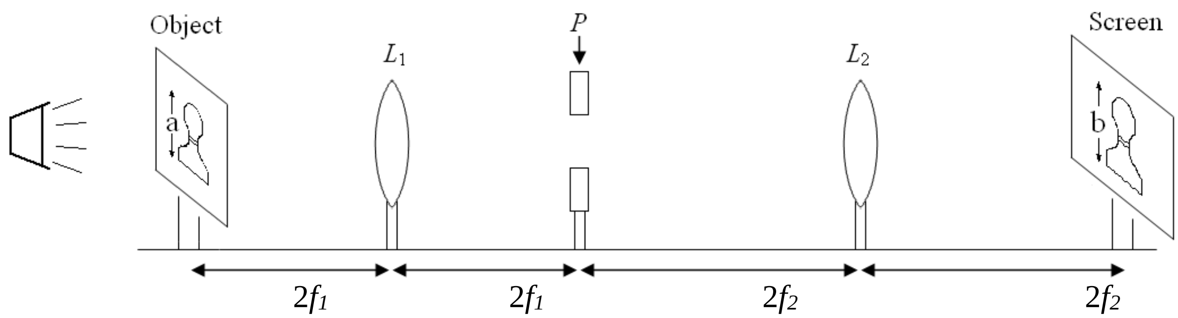
Experiment 3: Periscope, Telescope and Microscope PHY 431

In this experiment you will examine two basic optical systems: 1) periscope, which can also be operated as 2) a telescope, and 3) a reflection microscope. Periscope is a device that translates an image and projects it to a screen without inversion. The microscope is used here to examine the resolution of the characters produced by a laser printer. The background ideas include magnification of objects and the roles of stops and pupils in limiting some rays and thus improving image and angular magnification.

Procedure:

Periscope/Telescope

A. Set up the following system using two lenses of equal diameters, but not necessarily equal focal lengths. You may find it convenient to replace the screen with a reticle (a glass plate with an inscribed length scale). Construct a bright object by backlighting tracing paper with a halogen lamp. Define the object to have a diameter of just 1-2 mm with masking tape. You will probably need an iris between the lamp and the object to prevent stray light from impinging on the rest of the system. Note that light rays are also limited by the finite diameter of the lenses. Hence, L_1 plays both the roles of aperture stop and entrance pupil.



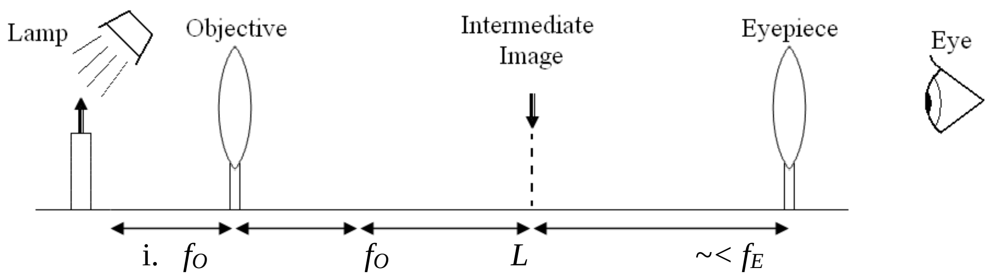
B. Use Eq. (1) of the Appendix (i) to find the magnification of the periscope M = b/a. Measure the object and image sizes to find M (including uncertainty). Compare the calculation and measurement.

C. Put a field stop at point P aiming to eliminate any blurring for the image.
Q1. What is the source of the blurring? (Hint: if you placed an object at the position of either lens, would it be in focus on your screen?)
Q2. Assuming that the blurring is related to the edges of the lenses, can you determine which lens is the culprit? Try putting the field stop at a position other than P.
Q3. How effective are the alternate positions? Can you explain the findings?

D. The system can now be used as a telescope by turning off the lamp and replacing the screen with your eye. You will find that you cannot immediately focus on the image. Move L_2 towards the object, until you are able to see it clearly through the telescope.
Q4. Why is it necessary to shift L_2? Now estimate the apparent magnification of the object from your current point of view. In other words, compare the angle subtended by the image θ_i to the angle subtended by the distant object θ_o. How does θ_i/θ_o compare to M?
Q5. Can you explain any discrepancy, if there?

Microscope

E. Use the same lenses to set up the following system



As an object use selected location on the paper covered with text printed using the lab's printer.

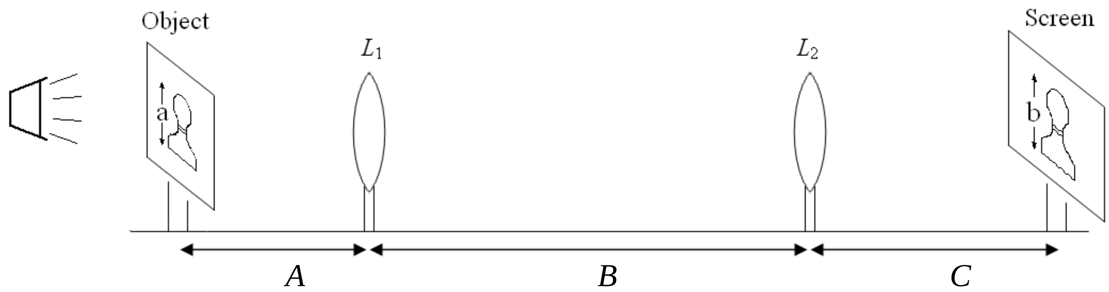
F. In the sketch above, the object is 1.25 f_O away from the objective lens. Draw a ray diagram for this case. Next draw a ray diagram for an object distance of 1.75 f_O, adjusting the placement of the eyepiece accordingly.
Q6. Is the magnification greater or less for the 1.75 f_O distance?

G. Set the object distance to about 1.5 f_O and focus the microscope.
Q7. Can you obtain a better image by reducing the magnification? If so, how can you explain this? You should find that the border of the field of view is fairly well-defined. If this seems surprising; remember that for the periscope we used a field stop to obtain a sharp border.
Q8. Why is the field stop not needed in this case?

H. Situate a camera at the place of your eye to take a picture. Make sure to get the image in focus (you may adjust the position of the eyepiece if necessary). Please include the picture in your report. Now that the characters are greatly enlarged, comment on the precision of the printer. Note that the lines and curves do not look perfectly sharp.
Q9. Are the imperfections consistent with the printer resolution of 1600 dots per inch? If not, what do you think is the origin of the less-than-ideal characters?

Appendix (i): Two-Lens System

Here is a description of the general system.



The image produced by the first lens L_1 is at position s_1' and is given by

$$\frac{1}{A}+\frac{1}{s_1'}=\frac{1}{f_1} \quad \text{so that} \quad s_1'=\frac{Af_1}{A-f_1}.$$

The object is at distance $B-s_1'$ for the second lens L_2 and the final image is at C so that

$$\frac{1}{C}+\frac{1}{B-s_1'}=\frac{1}{f_2} \qquad \text{so that} \qquad C=\left[\frac{1}{f_2}-\frac{1}{B-\dfrac{Af_1}{A-f_1}}\right]^{-1}.$$

The magnifications are $m_1=\frac{-s_1'}{A}$ and $m_2=\frac{-C}{B-s_1'}$, respectively, so the net magnification $M=m_1m_2$ is given by

$$M=\frac{f_1}{A-f_1}\frac{C-f_2}{f_2} \qquad (1)$$

Appendix (ii): More on Errors

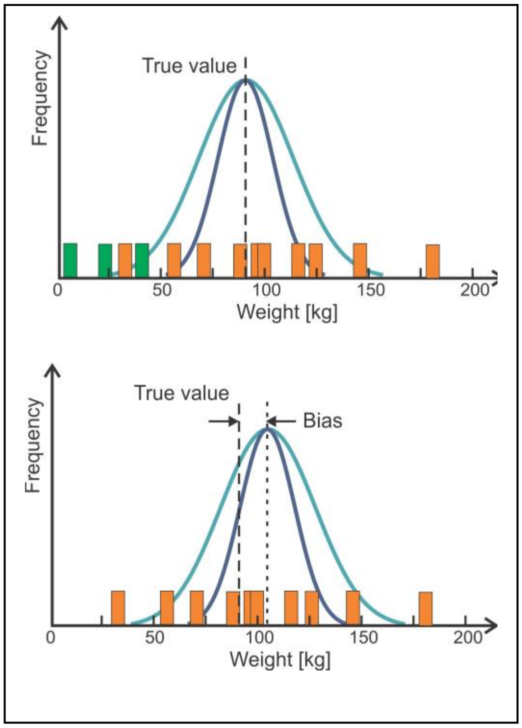
Random & Systematic Errors

Random and statistical errors are type of errors related, respectively, to precision and accuracy. Random errors vary between successive measurements. They are equally likely to be positive and negative. They tend to be always there in an experiment. Their presence is obvious from distribution of values obtained. Their impact can be minimized by performing multiple measurements of the same quantity.

Systematic errors are generally constant throughout a set of measurements. They may result from calibration of equipment or from methodology behind the measurements. They cause the mean of measured values to depart from the correct value. They can be difficult to estimate. At times the manufacturers provide accuracy of the instruments they supply. In absence of such information, one can assume that the systematic error is at least half of the last digit that the instrument provides in a measurement.

When few measurements are carried out, random (also called reading) errors tend to have more impact on the outcome of the measurements. However, if many measurements are carried out and the impact of random errors diminishes, the systematic errors begin to dominate the overall error.

As an example illuminating systematic errors, let us consider a situation where researchers are to determine an average weight of some population. If they select representative samples of the population, illustrated with boxes in the upper panel of the adjacent figure, errors are purely random. Following central-limit theorem, the distribution of the average weight for samples, Gaussian curves there, narrows as sample size increases, eventually becoming very narrow around the true average for the population. The width of the distribution can be estimated using the distribution of weight values for a sample. However, if the researchers make local arrangements such that they can only weigh those above the age of 10, illustrated with boxes in the lower panel of the figure, their samples begin to be biased towards higher values of weight. When their samples become very large, the distribution of the average weight for a sample becomes narrow, but it peaks around a value that is systematically in excess of the true average for the population. Increasing the size of a sample does not help to eliminate the bias. It is impossible to estimate the bias on the basis of a sample alone.



Understanding the nature of the bias, one can try to correct for it, e.g. using data for another population. However, even after such correction some residual systematic error will remain that the size of a sample will not help with. Other systematic errors may be due to the weighted individuals being in clothes, scale calibration etc.

For functions systematic errors are propagated in the same fashion as random errors, using partial derivatives when errors are small. For net final error, the one with random origin is added in quadrature to the systematic error:

$(\text{net error})^2 = (\text{random error})^2 + (\text{systematic error})^2$.

In the experiments done so far, the systematic errors stem e.g. from accuracy of the ruler and from approximating a thick lens with a thin lens. If error of random origin is large, the systematic error may be disregarded, but not if the random error for good or wrong reasons is small.

Stating Results and Errors

Generally state errors to 1-2 significant digits. Two digits are advisable, if the leading digit is low. Quote result to the same significance as error. When using scientific notation, quote value and error with the same exponent.

- Value 33, error 11 → 33±11
- Value 72, error 36 → 70±40
- Value 5.6×10^3, error 6×10^2 → $(5.6 \pm 0.6) \times 10^3$

Incorrectly stated results:

- 36±0.7
- 36.06±0.7