Week IV:  
FIRST EXPERIMENTS WITH THE ADVANCED OPTICS SET

The Advanced Optics set consists of
(A) Incandescent Lamp  
(B) Laser  
(C) Optical Bench (with magnetic surface and metric scale)  
(D) Component Carriers (with magnetic surfaces)  
(E) Angular translator  
(F) Linear (motor driven) Translator  
(G) Photometer  
(H) Variety of Optical Components (in fitted case)

These components and their proper operation are described in detail in “Equipment Instructions”, which can be obtained from the TA and which you should consult for specific questions on components.

☞ Before starting the experiment check out the new equipment.

a) Get familiar with the various optical components in the fitted case. Order them (label upside down) in such a way (lenses, filters, mirrors, polarizers, apertures, etc., together), that you will find what you need in your experiments.

b) Place incandescent light source on the left side of optical bench (front end at 20 cm mark). Press back edge of light source up against the alignment rail of the optical bench for lined-up position. The large knob on the top of the light allows you to move and adjust the bulb filament perpendicular to the optical axis.

c) Get familiar with the operation of the standard component carriers, which can be moved on the magnetic strip of the optical bench to any position. By pushing the short edge of the carrier base against the alignment rail of the optical bench, the carrier will be oriented perpendicular to the optical axis. The magnetic surface of the carrier allows the direct attachment of the optical components.

d) Get familiar with the angular translator and its operation and find out how the “special component carrier” is positioned on the angular translator.

e) Get familiar with the laser and its positioning on the optical bench.

CAUTION:
☞ DO NOT LOOK DIRECTLY INTO THE LASER BEAM OR ITS REFLECTION  
☞ DO NOT POINT THE LASER TOWARDS OTHER PEOPLE’S FACES!

Note: The output power is low enough so that the laser will not blind you right away. However, looking into the laser for a long time will damage your retina permanently. Moreover, this is a teaching lab and you should learn how to use lasers safely and responsibly.

The first experiments (IV.A-IV.D) are performed with incandescent lamp on left side of optical bench, with front-end at 20 cm mark. Note that for measuring the exact position for any component (lenses, etc.) on optical bench, you have to correct for the thickness of the component carrier and the thickness of the component itself (the lenses are not symmetric in their holders!). Try to correct for these displacements.
IV.A Imaging by a Single Lens *(Report errors in measured quantities and do error propagation)*

Experiment: Place 136 mm (or 127 mm) lens in the middle, and the screen on right side of optical bench. Find and measure (with fixed lamp and screen) the two positions of the lens which produce a sharp image of the filament on screen.

› Using the given focal length of your lens, determine the exact position of filament (that is, its distance from the front-end of lamp housing). Explain how you determine it.

› Determine the exact size of the filament by optical imaging techniques and application of simple lens equation. Explain how you determine it.

IV.B Depth of Field *(No error reporting required)*

Experiment: Same as above. Put a variable diaphragm close to lens. Observe that closing of its aperture does not change the image of the filament; it allows however to obtain a “reasonably good image” even when varying the object- or image-distance around the perfect situation.

› Why? Explain with a ray diagram.

› What does the observation have to do with the “depth of field” in photography (depth of field varies inversely with aperture size)?

› How would you construct a camera without a lens which always yields a sharp image?

IV.C Auto-collimation Method *(Report errors in measured quantities and do error propagation)*

Experiment: Use the illuminated (closed) diaphragm aperture as a point source to determine the focal length of the lens by the “auto-collimation method”. In this technique, the lens is placed close to the focal distance from the point aperture light source, and the beam emerging from the lens is reflected by a plane mirror back through the lens and imaged on the rim of the point aperture. Observation of the back-reflected spot under fine adjustment of the lens position allows a very accurate determination of the focal distance.

Hint: Make sure the back-reflected spot does not show the focused image of the bulb filament but instead shows the focused image of the aperture opening.

› How does the result compare to the given value of f? Explain how the method works using a ray diagram.

› You have used by now several methods (at least three) to determine the focal length of a lens. Judge yourself which one is the easiest (fastest) and which is the most accurate method. Give reasons.
IV.D  Spherical Aberration and Foucault Knife Test (*No error reporting necessary*)

**Background:** Spherical aberration is the phenomenon wherein rays passing through different zones of the lens come to different foci. Generally – and in our case – rays close to the optical axis are refracted less and come to a focus farther away from the lens than marginal rays (“under-corrected lens”). Thus there is no “exact” screen position where the image is “in focus”.

**Experiment:** With the incandescent lamp on the left, position the 18 mm double convex lens on the bench (about 30 cm away from the front end of light source). Attach on a component carrier a sharp razor blade vertically. Adjust the assembly position until a sharp image of the filament is positioned on the razor blade. Carefully adjust the razor blade on the carrier until the sharp edge cuts vertically across the center of the focused image. (For fine adjustment you can use the knob of the light source to slightly shift the lamp filament in order to center its image on the edge of the razor blade.) Put viewing screen to the right of the razor blade assembly and examine the image. It should resemble one of the patterns sketched below:

![Pattern Sketches](image)

Move the razor blade assembly or the lens slightly forward and backward along the optical axis, and observe the change of the pattern and record what you see (“Foucault Knife test for lenses”).

☛ Explain your observation with ray diagrams.

**Experiment:** Place a diaphragm centered in front of the test lens and observe how the pattern changes when you close it down.

☛ Describe and explain your observation.

☛ What would you observe for a lens without spherical aberration?
IV.E Total Internal Reflection and Refractive-Index-Determination of a Liquid (“Abbes’ Method”) (Report errors in measured quantities only)

Experiment: Position the laser on the optical bench, on the left side from the angular translator. (The latter with a viewing screen attached to the holder on the moveable arm.) Position the prism on angular translator so that the laser beam falls in normal incidence on one of the small prism faces. (Exact normal incidence can be checked by observing the beam reflected from the prism face.) Turn angular translator with prism, and observe refracted beam on screen on moveable arm (Fig. 1). Determine as accurately as possible the angle \( \Theta_{\text{crit}} \) (including its direction) at which total internal reflection occurs (Fig. 2).

☛ Determine the refractive index \( n_{\text{prism}} \) of the prism using only the measured angle \( \Theta_{\text{crit}} \).

Hint: You need to solve a system of 3 equations which describe
(i) the refraction on the first interface,
(ii) total internal reflection on the second interface, and,
(iii) a relation between the involved angles.
You can assume that \( \Theta \) is small. i.e., \( \sin \Theta \approx \Theta \).

Experiment: Obtain second prism (from neighboring set) and form a “composite cube with an “air gap” out of the two prisms attached along their diagonal faces (Fig. 3). Repeat the above experiment and observe onset of total internal reflections.

☛ Explain qualitatively the observed change of the single refracted beam into a series of beams close to the condition of total internal reflection.

☛ Is there any difference in \( \Theta_{\text{crit}} \) compared to above?

Experiment: Obtain (from the TA) liquid to be tested and produce a thin film of liquid between the two diagonal prism faces. Observe the reappearance of the refracted beam when inserting the liquid, and measure accurately (by turning the angular translator) the new critical angle for total internal reflection. Note again the direction of \( \Theta_{\text{crit}} \).

☛ What can you conclude instantly about \( n \) of the liquid from the reappearance of the transmitted beam?

☛ Determine the refractive index of the liquid \( n_{\text{liquid}} \) from the measured angle \( \Theta_{\text{crit}} \). Note: You can no longer treat \( \Theta_{\text{crit}} \) as small. You may use \( n_{\text{prism}} \) obtained above.
Background: You first use the laser as a source of a good “parallel” light beam, which you will expand or contract in diameter with the help of lenses (based on the principles and setups of telescopes).

Note: During these experiments, however, you will observe, that the laser beams are not ideally parallel, but have a small angular divergence which depends characteristically on the beam diameter. This problem will be treated later in class under diffraction.

☛✍ How can you expand a parallel beam with a Kepler- and Galilean-type telescope set-up?
☛✍ How can you change from an expander to a contractor? What are the expansion and contraction ratios?

Experiment: Set up the laser on the left side of the optical bench. Use the available lenses to first expand the laser beam. Test its parallelism.
☛✍ Measure the beam diameters before expansion and after expansion. Compare the result with the expected ones.

Experiment: Use the expanded beam from the above and contract it by building a second “telescope” with the remaining lenses.
☛✍ Measure the contracted beam diameter and compare with the expected value.