Optical Micrometer

The light source for this experiment is a low-power helium-neon laser with a wavelength of 632.8 nm. **Never look directly at a laser beam nor permit anyone else to do so!** Exposure to the direct or reflected beam for more than a few seconds will cause serious eye damage. Do not pick up the lasers and shine them around the room. If these simple precautions are taken then there will be no risk associated with the lasers as they are of relatively low power.

Theory

The two basic principles of geometrical optics are the law of reflection and the law of refraction (Snell's Law). The law of reflection states that the angle of incidence is equal to the angle of reflection, both angles being measured from the normal to the surface, and that the incident ray, the normal and reflected ray are coplanar.

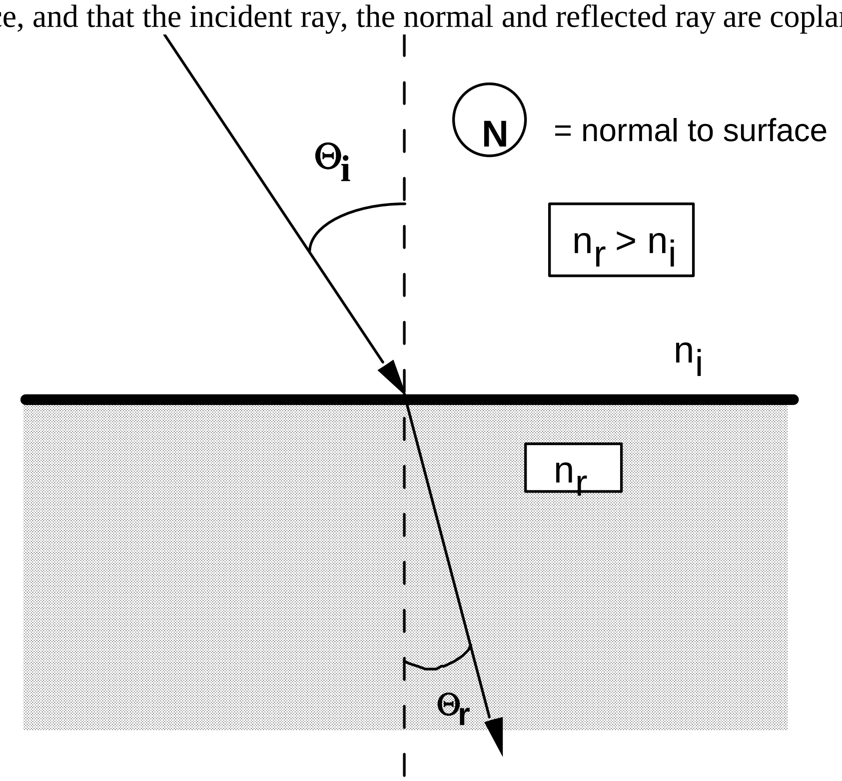

Fig. 1: Diffraction at an interface between dissimilar media

Snell's law states that the incident ray, the refracted ray and the surface normal are coplanar and that:

$$\boxed{n_i \sin\Theta_i = n_r \sin\Theta_r} \quad (1)$$

where n_i and n_r are the indices of refraction of the two media involved. The medium with the larger index of refraction is said to be optically denser than the one with the smaller index. If the ray goes from the optically less dense to the optically more dense medium, then it is refracted toward the normal. If the ray enters from the optically more dense medium, it is refracted away from the normal. In that case, the maximum possible angle of refraction is 90° and the corresponding angle of incidence is then (from Eq. 1):

$$\Theta_i = \Theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right) \qquad (2)$$

which is called the critical angle. If the angle of incidence is larger than the critical angle, there cannot be a refracted ray and the beam is totally internally reflected.

A light ray traversing a plate of material with parallel entrance and exit faces is displaced laterally without a change in direction. This displacement effect is very useful for laser surveying and laser control of instruments. With high-quality apparatus, displacements as small as one-tenth of one millimeter can be measured and controlled over sizable distances. It can be shown from Snell's law that the lateral displacement "d" of the beam is given by:

$$d = \frac{D}{\cos\Theta_r}\sin(\Theta_i - \Theta_r) \qquad (3)$$

where D is the thickness of the material which the beam traverses and Θ_i , Θ_r are the angles of incidence and refraction of the entering beam. [The roles of these two angles are reversed for the exit beam].

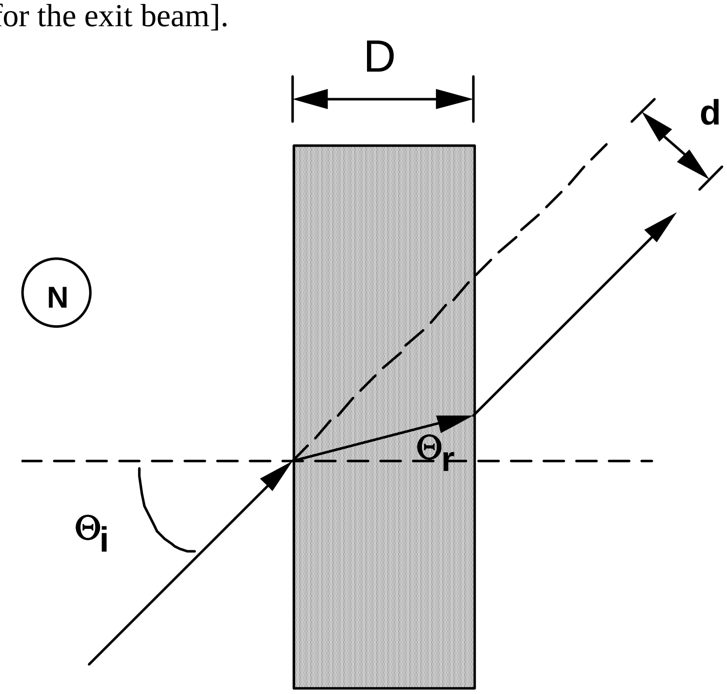

Fig. 2: Refraction through a slab.

Procedure

Be sure to make sketches of all your setups and indicate trajectories of rays.

1. Set up the optical table so that the laser beam is parallel to the surface of the table, 2 to 3 mm above it, and traverses the table directly above the zero degree median line of the protractor circle. Beam positions can always be easily located by interposing a file card into the path of the beam.

2. Mount the semicircular lens on the protractor circle with the flat surface facing the laser. Autocollimate the beam by moving the wooden platform until the reflected beam bounces back into the opening on the laser face. You might not actually see this, but you can see when the reflected beam hits to the right or to the left of the opening and adjust accordingly. Make sure that the beam is positioned in the center of the semicircular lens. Why is this important?

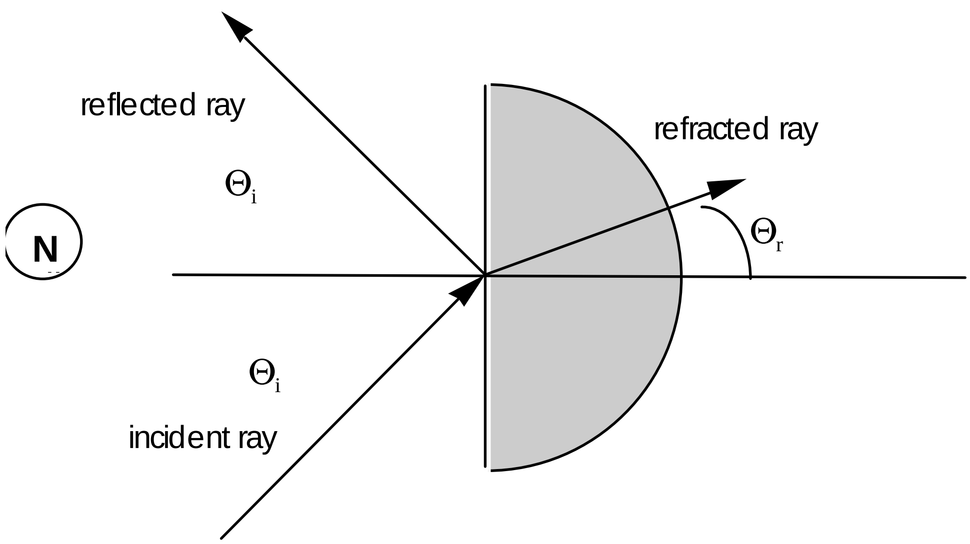

Fig. 3: Reflection and refraction from a semicircular lens.

3. Record the position of the refracted laser beam for a series of incident angles in 10° steps. Note that the beam leaves the lens at right angles to the curved surface and is therefore not refracted on leaving. Be careful to not move the optical table between measurements. Qualitatively observe the intensities of the reflected and refracted beams as the angle of incidence is varied.

4. For each of your measurements separately, calculate the index of refraction of the plastic material from Snell's law, then average your calculated values to get the mean value and determine the standard deviation and the standard deviation of the mean.

5. Repeat with the curved surface toward the laser, again observing the behavior of the beams reflected and refracted at the flat surface. Note that the entering beam is not refracted. Again observe the intensities qualitatively for angles of incidence smaller and larger than the critical angle. Determine the critical angle, the index of refraction from it. Repeat this measurement of the index of refraction several times, then compute the mean value and the standard deviation for the mean of the index of refraction and compare it to your previous measurement (in step 4).

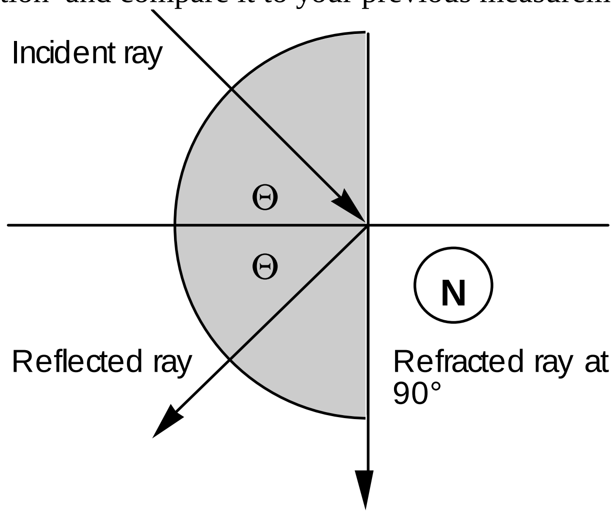

Fig. 4: Total internal reflection.

6. Mount the flat plate. Autocollimate the beam. Record the lateral displacement "d" of the laser beam for a series of angles of incidence in 10° steps. Measure "d" at a near point and at a far point from the optical table and measure the distance L between your near and far points of observation. Measure the thickness of your plate "D" with a caliber. (If you don't know how to read the vernier scale, ask.) Estimate your measurement errors for "d" and "D".

7. For each of your angles of incidence separately, calculate the displacement "d" from Eq. 3, using the value for the index of refraction measured in part 4 above. Compare your calculations with the measured values of d.

8. In practice, the laser beam may emerge not only displaced laterally, but also making some angle Θ_{dev} with respect to the incident path. Use the equation:

$$\Theta_{dev} = \frac{d_{far} - d_{near}}{L} \qquad (4)$$

to calculate the angle of deviation and its uncertiainty for each of your measurement sets and discuss your findings. Note that the angle can be either positive or negative.

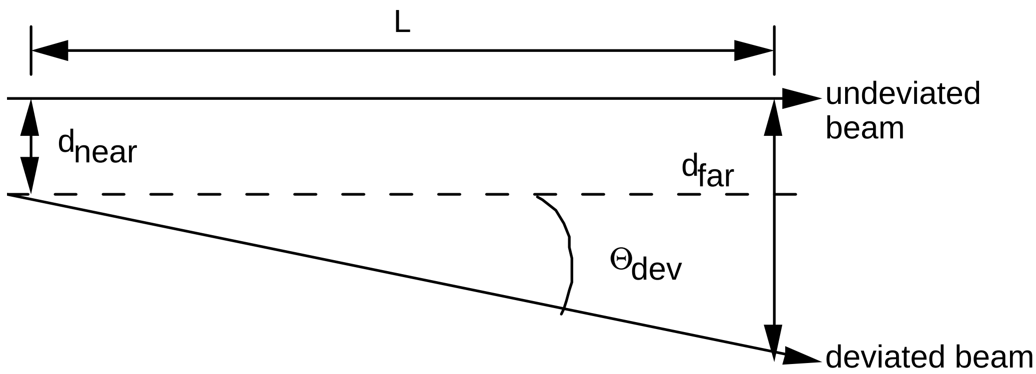

Fig. 5: Deviation of beam going through slab.