EXPERIMENT 2

Pfund refractometer

1. Index of refraction by total internal reflection

One of the simplest devices for determining an index of refraction was invented by A. H. Pfund. A description appears in Physical Optics by R. W. Wood (p. 70, third revised edition) from which this experiment is drawn.

A glass plate of thickness t is illuminated from the top. In our experiment we will use a He-Ne laser and a mirror as shown in the sketch in Figure 1.

The laser light passes through the upper surface and strikes the lower surface of the plate. In Pfund's original design, this surface was painted white, but in our experiment we will use a white piece of paper and later add some glycerin to illustrate just how this works. If you have just a piece of paper, the light passes through the lower surface and is scattered by the paper. This spot now is a new source, sending rays back through the plate. The rays continue to the upper surface where some are reflected back down. If the returning rays encounter the lower surface at less than the critical angle they leave the plate and strike the paper again. The paper is therefore illuminated with a bright disk of light, centered on the laser spot.

For light incident on a surface from inside the glass, there is a critical angle of incidence θ_c above which all light is totally reflected and none is transmitted. The critical angle determines the size of the circles of light seen in the Pfund refractometer. The diameter of the disk is given by

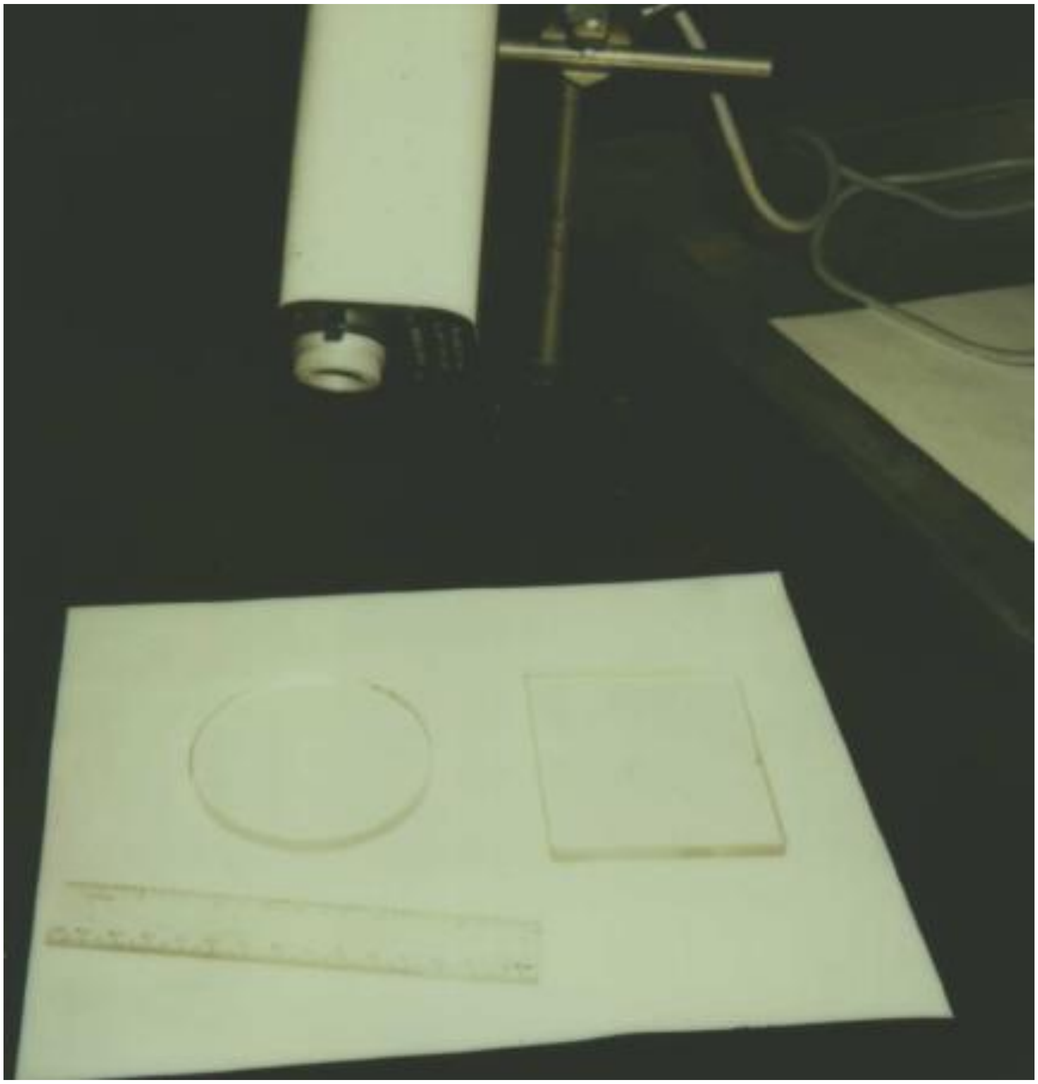


Figure 1: Without optical contact at the paper, the steepest angle for light inside the plate is just the critical angle. The paper is illuminated by a circular disk of light. With glycerin between the glass and the paper, light reenters the plate at all angles after it scatters from the paper. Total reflection at the upper surface illuminates the paper with a pattern complementary to the one without a liquid.

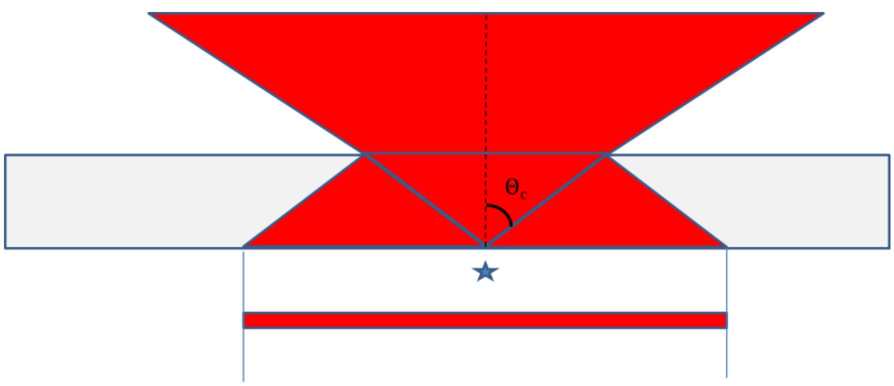
$$D = \frac{4\,t}{\sqrt{n^2-1}} \qquad (1)$$

Here n is the index of refraction of the glass relative to the surrounding air and t is the thickness of the plate.

2. Find the index of refraction of glass

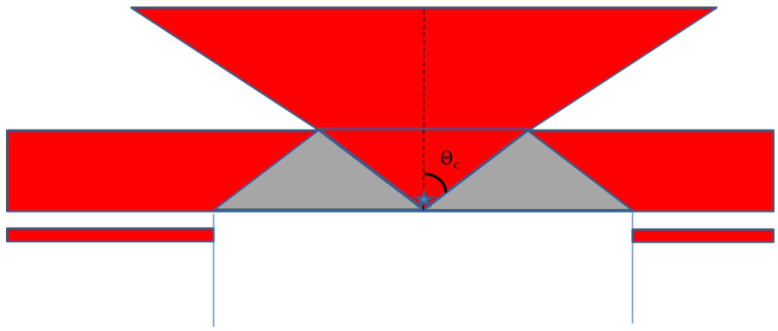
Look for a disk of light

Measure the diameter of the disk as shown in Figure 1. Pfund and Wood claim that with a traveling microscope the measurement can be made to about 0.1 mm. Using a ruler you can probably achieve an accuracy of 0.5 mm with care. Measure the thickness of the glass with calipers and calculate the index of refraction of the glass from Equation (1).



Use a white lower surface

If the lower surface is painted, the light scatters from the paint and reenters the glass at all angles, because the indices of refraction of the paint and the glass are comparable. This backscattered light is incident on the upper surface at all angles. For those angles less than the critical angle, light can be transmitted through the upper surface and back toward the laser. For angles greater than the critical angle, the light is totally reflected back toward the painted lower surface. The light exits the glass, and illuminates the paint. Thus we see a dark circle, surrounded by brighter ring of light.



You can demonstrate this effect by using a little glycerin to optically contact the paper and the glass. Glycerin has an index of refraction of 1.47 which is quite close to that of the glass. Take a piece of paper, place a few drops of glycerin on it, and set the glass plate down on the paper. The fluid should fill the gap between the paper and the glass completely. The two materials are then said to be in optical contact. Illuminate the disk as before and notice the new appearance of the pattern of light. Describe what you see. Measure the diameter of the disk again. Compare these observations with those you made without the paper.

Figure out why this happens

Derive Equation (1) given above. Show that the same equation describes the diameter of the dark circle in the second example. Explain why the light can leave the glass and scatter from the paint at the lower surface, but is totally reflected for the same angle of incidence at the upper surface.

3. Find the index for water

Put a drop on the top surface

With the painted or glycerin-paper lower surface, this device is useful for determining the index of refraction fluids. Continue with the arrangement using paper and glycerin.

While the laser illuminates the glass, place several drops of water on the upper surface. Keep water out of the glycerin-paper layer by using just enough on the upper surface to make a pool covering most, but not all, of the glass. Notice the new appearance of the illuminated area. Describe what you see. You should find a circle with increased diameter that is due to reflection from the glass-water surface. The equation given above still applies, but n is now the relative index of refraction

$$n = {}^{n_{glass}}/_{n_{water}} \qquad (2)$$

From the diameter of the circle in this case, and the index of the glass found before, determine the index of refraction of water.

You've seen it, explain it

Explain the necessity of having either paint or glycerin-paper in order to determine the index of a liquid on top of the glass. Differentiate the equation for n and estimate the error in the determination of n_{water} by Pfund's method.