Refractive Index of Glass – Pfund's Method

1. Pfund's Method

Refractive index is an important property for optical uses of glass, and in this lab we explore how to measure this basic parameter. Our simple approach is based on Pfund's method [1], where only a laser pointer and a ruler (or caliper) are required to determine the refractive index of a thick, flat sample of a transparent material. If a transparent glass sample is illuminated with a laser pointer as shown in figure 1, then an abrupt change in reflected light will occur at the critical angle. The vanishing transmission below the critical angle produces a dark region of radius, r, around the center spot. The refractive index can be calculated from the radius of the dark region and the thickness of the sample, h, using the simple expression, $\mathbf{n^2 = 1 + (2h/r)^2}$. The dark center will be observed when the back of the slab is frosted or when the sample is in intimate contact with a light colored base (e.g. grid paper). In the case where there is an air interface on the bottom surface, such as a polished optical flat, then the light ring is observed in the center at the same condition. You can see this transition from light interior to dark interior by using a thick optical flat on a piece of dry paper followed by wetting the paper (which allows reflection through the bottom interface above the critical angle).

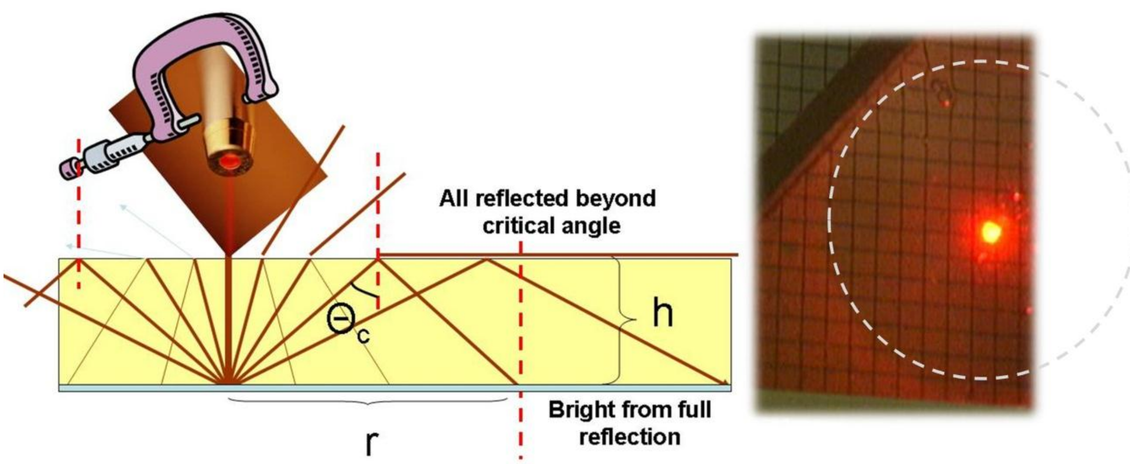


Figure 1. Basic concept of Pfund's method for measuring the refractive index of a transparent plate. Photo on right shows a darker region in the center of sugar glass slab molded on grid paper.

The method is accurate to about 1-2% if sample is very flat and of clear optical quality. Moreover, it illustrates the phenomenon of total internal reflection quite clearly and provides a hands-on application of the link between refractive index and critical reflection.

Samples:

Two issues limiting the accuracy of this method are the finite spot size of the laser (ideally a point) and how well you can accurately determine the diameter of the ring (which may not always be crisp). Thicker sample with their corresponding larger ring diameter will be less affected by either of these issues. Thus we recommend having the student begin with a thick glass plate to make their measurements. Optical "flats" provide an ideal choice as they are usually constructed of thick glass to provide the dimensional stability. In general optical flats are a precision optic and can be quite expensive. Fortunately there is a surplus market where they be obtained for a reasonable price [2]. We recommend using something on the order of 1 cm thick, which will result in a ring diameter on the order of 3.8 cm (1.5''), so that the spot size error is minimal. Some specific options are listed in the notes [3] together with the current price.

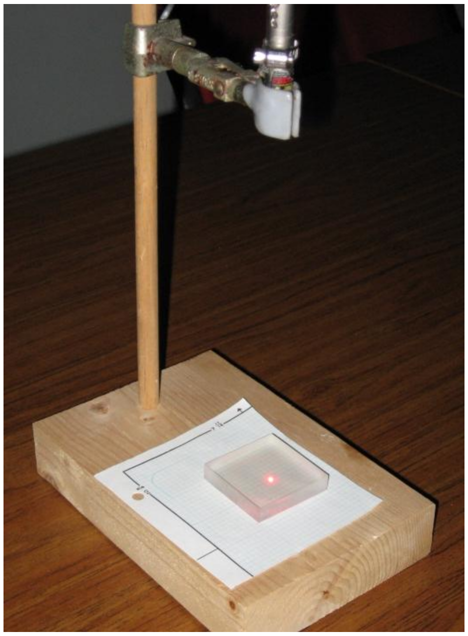
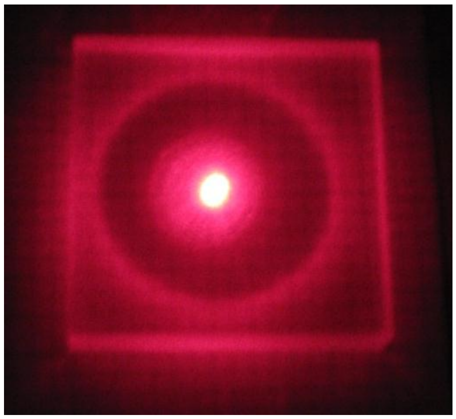


Photo of setup used by author. Note use of wood dowels and 2x8" to keep cost low. Laser is held with a utility clamp available in most labs and the laser power button is kept in "on" position with a small hose clamp which can be slid off the on button to turn off.

If the ambient lighting of a classroom is too bright to see the ring clearly, the observer may wish to have a thin, dark covering (like a scarf) to cover themselves and the apparatus while viewing and taking measurements.



Notice how the grid paper can be used to provide a moderate resolution measurement of the ring diameter.

Laboratory Activity - Pfund's Method

Part A: Thick piece of standard oxide glass – getting familiar with the method
Place the thick piece of glass provided on a sheet of grid paper and direct a laser pointer through the disc (normal to the plane). You may wish to use a ring stand and clamp to hold the laser steady. Observe the circular region of light/dark produced around the laser spot. Using a ruler, calipers or the grid paper, measure the diameter of the ring. Also measure the thickness of the glass plate.

Describe the nature of the inner circle. Is it darker or lighter than the outer region?

Diameter of inner region: ______ mm.

Thickness of the plate: ______ mm.

Using the above information and figure 1, calculate the thickness to radius ratio (h/r= 2h/d) and the corresponding index of the glass, n. (n = sqrt {1+ $(2h/r)^2$}

The glass sample was a low expansion borosilicate glass (like pyrex) which has an index of refraction of ~ 1.47. Compare your result with this value. Calculate the % difference.

Extra: Put the optical flat on a wet paper towel and see if it changes your result. Or put it in a dish of water and explain the changes you observe.

Part B: Thick piece of sugar glass

Making the samples:
Using the sugar glass recipe described previously[4], prepare flat slabs of sugar glass approximately 1 cm thick by pouring the molten candy solution into circular molds. The molds can be made from hose clamps or from 0.5" wide strips of card paper formed into a ring (approximately 3" in diameter). The rings should be placed on a sheet of grid paper (to make measurement of light ring easier), and tape of modeling clay can be used to keep the rings from moving during the pour and subsequent cool. After cooking the candy mixture allow it to rest for a few minutes before pouring to make sure there are no bubbles in the mixture. After pouring allow the material to cool to room temperature where it should have a hard glass-like consistency.

After cooling, use the laser to observe the ring of light/dark formed from the total internal reflection at the critical angle. Measure the diameter of the ring. Also measure the thickness of the sample. If the sample has a thickness variation towards the center, try to measure the thickness near the edge of the dark inner circle. Record both below and calculate the refractive index of the sugar glass.

Diameter of inner region: ______ (units=).

Thickness of the slab: ______ (units =).

h/r = 2h/d =

n =

Extra Challenge: Considering that the refractive index of water is about 1.33 and a reasonable estimate for the index of a pure sucrose "solution" might be taken as 1.558 (as per Feynman in his famous lectures [5]), does your measurement make sense? Explain your reason.

Part C: More advanced RI experiment with Pfund method and sugar glass:

In the recipe for making sugar glass[4] we gradually boil off the water until we reach the desired water content as monitored by the boiling temperature (above 150º C). One could extract samples form the boiling solution at various temperatures along the way (say from 130 to 155° C) and, after cooling, measure how the refractive index changes with boiling temperature. Furthermore by using the analysis presented in the Feynman paper in the notes [5], one could estimate the fraction of water from the refractive index. (Essentially assuming that refractive index of the solution is a compositionally weighted average of the index of water and pure sugar). This could make a great science project for the dedicated student.

2. Refractive Index Using a Student Spectrometer – Minimum Deviation Method

Another, more accurate method utilizes a student spectrometer and a prism of candy glass formed within a glass mold constructed by the student from glass slides. The minimum deviation method [6] allows the student to obtain the refractive index to four significant figures, while quantitatively exploring the nature of refraction. Each of these methods has been tested and described in detail by undergraduate students during IMI-NFG's summer REU programs at Lehigh University. Full presentations of their procedures and results are available on our website.

One of our students utilized the minimum deviation method to determine the refractive index of candy glasses over a wide range of sucrose to corn syrup ratio and found no significant variation of refractive index, consistent with the observed uniformity of densities.

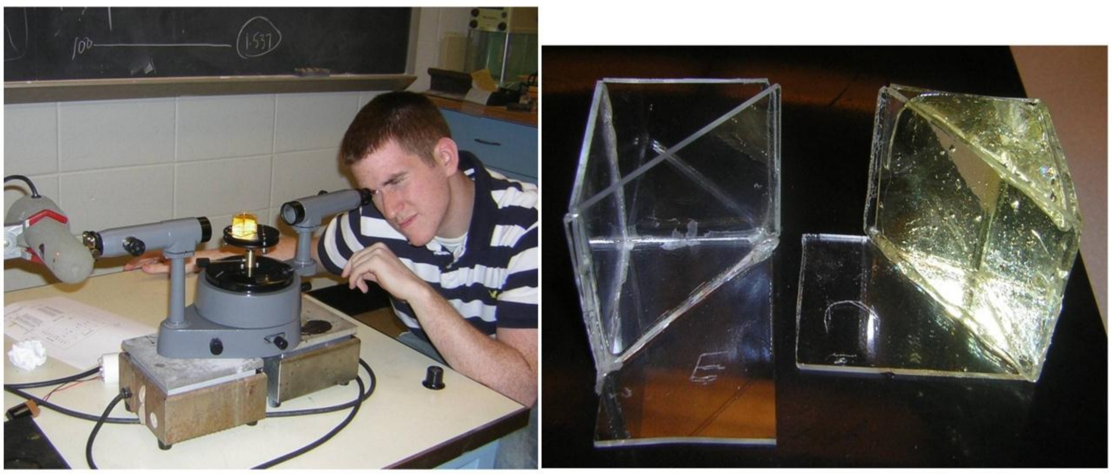


Figure 3. Left, an REU student measures the refractive index of a candy glass prism. Right, empty and candy filled prism molds made from microscope slides by the student.

Prepared by Bill Heffner as part of the glass science learning curriculum of the International Materials Institute for Glass. Please share any thoughts and comments with the author at wrh304@lehigh.edu

Notes and References:

1. C. Harvey Palmer, *Optics: Experiments and Demonstrations* (The John Hopkins Press, Baltimore, 1962), p. 9.

2. One very good source for low cost surplus optics is the Surplus Shed at http://www.surplusshed.com/

3. Lower cost optical flats available from Surplus Shed (above) with current pricing.
● PM1250 50mm square LEBG not Aluminized Mirror Blank,
(This is 10 mm thick optical flat of low expansion borosilicate glass (LEBG), n=1.47 with one side polished and back side ground (rough), providing an ideal sample for Pfund's method).
Price: $6.00 or 10 for $50.00
● PM1246 30 mm diameter LEBG not Aluminized Mirror Blank, 6mm thick
Closeout Price: $3.00 ea.

4. See recipe for sugar glass at IMI website:
http://www.lehigh.edu/imi/pdf/CandyGlassRecipe.pdf

5. Feynman discussed the sugar water mixture in his famous series of lectures (Vol. 2, Section 32 on Refractive index of Dense Materials, page 32-9). There he provides an estimate of the index of randomly oriented crystalline sucrose as 1.558, which provides a reasonable estimate of the sucrose water "solution" with no water. I found a copy of these lectures available online at a website for Croatian physics and geophysics students and alumni at:
http://student.fizika.org/~jsisko/Knjige/Opca%20Fizika/

6. Arthur Hardy and Fred Perrin, *The Principles of Optics* (McGraw-Hill, New York, 1932), p. 548.