6. Dispersion and Total Internal Reflection

6.1. Equipment

Light ray box, cylindrical lens, ray plate, viewing[1] screen, sticky tac

6.2. Introduction

In this experiment you will look at two phenomena related to refraction: Dispersion and Total Internal Reflection. Dispersion introduces a complication to the Law of Refraction, which is that most materials have different indexes of refraction for different colors of light. n is now $n(\lambda)$. In Total Internal Reflection, it is found that in certain circumstances, light striking an interface between two transparent media can not pass through the interface. All the light is reflected back.

6.3. Theory

6.3.1. Total Internal Reflection

Snell's law below dictates that the path of a light ray crossing the boundary between two transparent materials will conform to

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \tag{6.1}$$

where θ_1 is the angle of incidence, θ_2 is the angle of refraction and n_1 and n_2 are the respective indices of refraction for the materials. These values are shown on the left of Figure[2] 6.1.

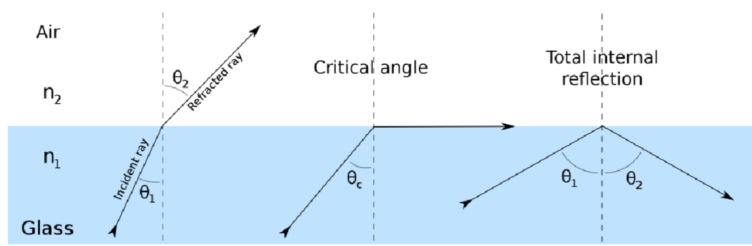

Figure 6.1.: Refracted ray moving from high to low optical density

For the case of a ray passing from a high n_1 to a low n_2 material, there exists a critical angle at which no light is refracted out as shown in the center figure. Using the acrylic material ($n_1 \approx 1.5$) and air ($n_2 \approx 1$) as the two media, there will be an $\theta_1 = \theta_c$ for which the ray stays just in the acrylic. In this case $\theta_2 = 90°$ and equation 6.1 becomes

$$n_1 \sin\theta_c = n_2 \sin 90°$$

Solving for the critical angle gives

$$\theta_c = \arcsin\frac{n_2}{n_1}$$

If one of the indexes is known and θ_c measured, the other index can be calculated.

[1] angled plate and paper or lens holder from OS-8501 Michelson Interferometer, white paper, magnets or some equivalent.
[2] "RefractionReflection" by Josell7 - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:RefractionReflextion.svg#mediaviewer/File:RefractionReflextion.svg

Table 6.1.: Dispersion parameters

Fraunhofer Line	Color (atom)	wavelength nm
F	blue (hydrogen)	486.1
D	yellow (sodium)	589.3
C	red (hydrogen)	656.3

6.3.2. Dispersion

The above theory assumes that either n never changes or that the light is monochromatic and so θ_c has one value. It will be seen that this is not completely true; there is a small range of critical angles. The light being used for this experiment is polychromatic and contains a mixture of wavelengths. In a vacuum the velocity of all wavelengths of light is the same and denoted c. In any medium the velocity of light is usually denoted v where v is a function of λ. Thus n is also a function of λ:

$$n(\lambda) = \frac{c}{v(\lambda)}$$

This results in the angle of refraction θ_2 being different for different colors of light: $\theta_2 = \theta_2(\lambda)$ for the refracted ray. This produces an effect called *dispersion*. Dispersion is utilized in the prism spectrometer to investigate the emission spectra of gases. Many years ago this stimulated the development of physical models of the atom and with that, quantum mechanics.

Figure 6.2[3] shows "dispersion curves", the dependence refractive index has on wavelength for a few types glass.

The dispersion effect will be observed when looking for the critical angle. It is quantified by a quantity called the dispersive power[4] D. It is calculated using Equation 6.2.

$$D = \frac{n_F - n_C}{n_D - 1} \tag{6.2}$$

The various values of n correspond to rays of wavelength λ_F, λ_D and λ_C which were arbitrarily chosen. These wavelengths are in the blue (λ_F, n_F), the yellow (λ_D, n_D), and the red (λ_C, n_C) regions of the spectrum. See Table 6.1. The numerator calculates a measure of the Δn using values at each end of the visible spectrum. n_D represents a midpoint or average value of the materials refractive index. Thus the greater the value of D, the greater the dispersion and the greater the range of angles at which various wavelengths are refracted.

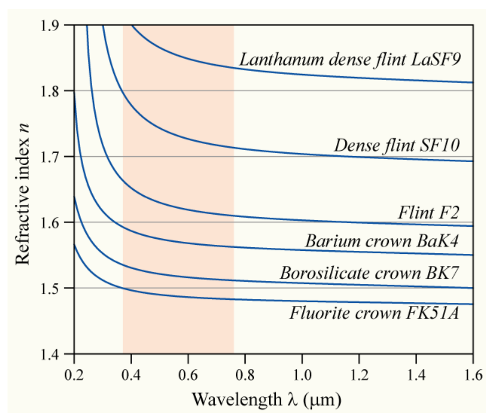

Figure 6.2.: Dispersion: Refractive index n as a function of λ

6.4. Procedure

Set up the equipment as shown in Figure 6.3.

1. Set the ray box for one ray and position it close to the ray table. Use sticky tac to keep the ray table from moving.

2. Align the beam so that it passes over the Normal line of the ray table.

[3] "Dispersion-curve" by Original uploader was DrBob at en.wikipedia - Transferred from en.wikipedia. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Dispersion-curve.png#mediaviewer/File:Dispersion-curve.png

[4] or dispersive ability

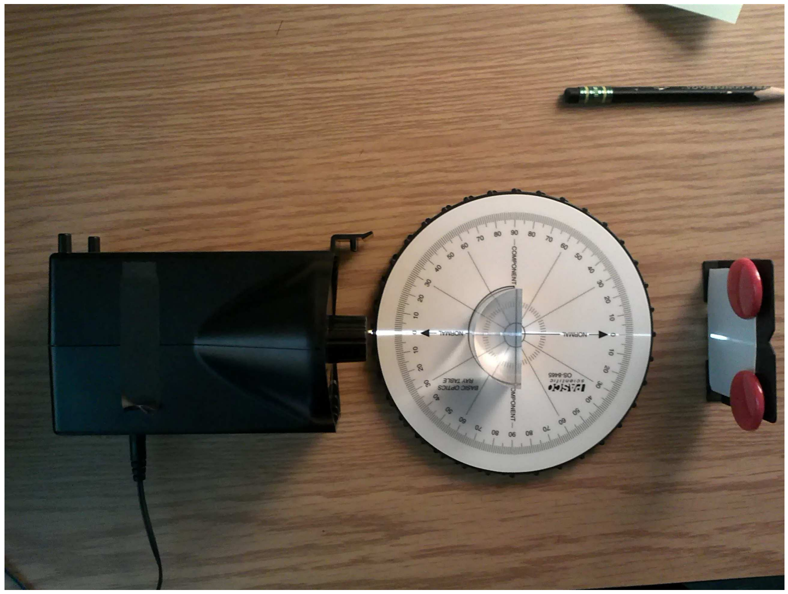

Figure 6.3.: Equipment setup for Total Internal Reflection and Dispersion.

3. Place the cylindrical acrylic lens on the ray table and align it with the component outline. The ray exiting from the lens should still pass over the Normal line. Any reflected ray(s) should go back toward the light source.
4. Place the viewing screen in a position to catch the exit ray. Move the screen as required.
5. Slowly increase the angle of incidence and observe the exit ray on the screen. Answer the following questions.

6.5. Questions

6.5.1. Dispersion

1. At what angle do you begin to see color separation in the refracted ray?
2. At what angle of refraction is the color separation a maximum?
3. List the colors present in the refracted ray in order of minimum to maximum angle of refraction.
4. Measure and state the values of critical angle with error for a)red and b)blue light.
5. Calculate the index of refraction of acrylic for a) red light and b) blue light with error.

6.5.2. Total Internal Reflection

1. From which surface of the lens does reflection primarily occur?

2. Is there a reflected ray for all angles of incidence? The screen or another piece of paper can be helpful in detecting faint rays.

3. Are the angles of reflection consistent with the law of reflection?

4. Is there a refracted ray for all angles of incidence?

5. How does the brightness of the a)reflected ray and b) the refracted ray change with increasing angle of incidence?

6. At what angle θ_C is all the light first reflected? Put a reasonable error on your angle.