Refraction Notes

Refraction:
1. The bending of a wave as it passes at an angle from one medium to another.
2. Caused by the changing velocity of the wave as it passes into the new medium.
3. “Light” will be our focus but other waves do this also.

Results:
1. When light enters a medium that slows it down, it will bend towards the normal.
2. When light enters a medium that speeds it up, it will bend away from the normal.

Determining Refractive index Activity:
1. Using a laser pointer, send a beam of light into the top of the block at an angle that allows the beam to exit the block from the bottom. (The steeper the angle the better, but it must enter the top and leave the bottom!!)
2. Just like in our mirror lab trace the block and the pathway of the laser beam.
3. Insert the normal for each boundary interaction.
4. Calculations to be done later! Keep for now!
5. Determine the angles needed to use Snell’s Law to solve for the refractive index of the block. Calculate both entering the block and leaving the block.
6. Average your two answers. Show all work on same paper.

Applet 1
Applet 2
Index of Refraction: How much will it change?

\[
n = \frac{c}{v}
\]

\[n = \text{index of refraction}
\]

\[c = \text{speed of light in a vacuum}
\]

\[v = \text{speed of light in the medium}
\]

From what we know about the speed of light what is the lower limit for \(n\)?

Index of refraction for air is 1.00 and water is 1.33. You must memorize these. All others will be provided.

<table>
<thead>
<tr>
<th>Material</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1.000000</td>
</tr>
<tr>
<td>Air at STP</td>
<td>1.00029</td>
</tr>
<tr>
<td>Ice</td>
<td>1.31</td>
</tr>
<tr>
<td>Water at 20 C</td>
<td>1.33</td>
</tr>
<tr>
<td>Acetone</td>
<td>1.36</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>1.36</td>
</tr>
<tr>
<td>Sugar solution (30%)</td>
<td>1.38</td>
</tr>
<tr>
<td>Fluorite</td>
<td>1.433</td>
</tr>
<tr>
<td>Fused quartz</td>
<td>1.46</td>
</tr>
<tr>
<td>Glycerin</td>
<td>1.473</td>
</tr>
<tr>
<td>Sugar solution (80%)</td>
<td>1.49</td>
</tr>
<tr>
<td>Typical crown glass</td>
<td>1.52</td>
</tr>
<tr>
<td>Crown glasses</td>
<td>1.52-1.62</td>
</tr>
<tr>
<td>Spectacle crown, C-1</td>
<td>1.523</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>1.54</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>1.55-1.59</td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>1.63</td>
</tr>
<tr>
<td>Flint glasses</td>
<td>1.57-1.75</td>
</tr>
<tr>
<td>Heavy flint glass</td>
<td>1.65</td>
</tr>
<tr>
<td>Extra dense flint, EDF-3</td>
<td>1.7200</td>
</tr>
<tr>
<td>Methylene iodide</td>
<td>1.74</td>
</tr>
<tr>
<td>Sapphire</td>
<td>1.77</td>
</tr>
<tr>
<td>Heaviest flint glass</td>
<td>1.89</td>
</tr>
<tr>
<td>Diamond</td>
<td>2.417</td>
</tr>
</tbody>
</table>
Snell’s Law

\[ n_1 (\sin \theta_1) = n_2 (\sin \theta_2) \]

- \( n_1 \) = refractive index of original medium
- \( n_2 \) = refractive index of new medium
- \( \theta_1 \) = angle of incidence (from normal)
- \( \theta_2 \) = angle of refraction (from normal)

Total Internal Reflection:
1. The complete reflection of light at a boundary between two different media.
2. Only occurs when moving from a medium of higher index of refraction to lower index of refraction.
3. The angle of incidence must be greater than the critical angle.

[Applet 0] [Applet 1]
Critical Angle:
1. The **minimum** angle of the incident ray to produce total internal reflection.
2. At the exact critical angle, the refracted ray runs parallel to the boundary.
3. The refracted ray will be 90° from the normal.

\[ \theta_1 = \theta_c \quad \theta_2 = 90^\circ \]
\[ n_1 (\sin \theta_c) = n_2 (\sin 90^\circ) \quad \sin 90^\circ = 1 \]
\[ n_1 (\sin \theta_c) = n_2 (1) \rightarrow (\sin \theta_c) = \frac{n_2}{n_1} \]

Critical Angle: Take what you did yesterday and calculate the critical angle from the class average!

Fiber optics: Total internal reflection example.
Critical Angle Activity

Obtain a laser pointer, 2 sheets paper, one angled block and a mirror.

First piece of paper
1. Direct the laser **perpendicular** to the short side (NOT the hypotenuse side). Where does the beam come out?
2. Mark the beam going in and out and trace the block. Draw pathway for the light.
3. At what angle is the laser hitting the backside of the block? Does this make sense that it should internally reflect based on the critical angle we calculated yesterday? Why?
4. Now replace the polycarbonate block with the mirror.
5. Put the mirror in the same location as where the hypotenuse was from the block.
6. Shine the laser along the same path as before.
7. Do you see a difference in the pathway compared to the block? Why or why not?

Second piece of paper
8. Finally, on the second sheet of white paper find the critical angle experimentally.
   a. Start by pointing the laser perpendicular to the short edge like before.
   b. Change the angle (think which way you should turn the laser) of the laser until you see the light beam coming out the hypotenuse side. (It should run straight down the hypotenuse)
   c. You can set up a mirror to help find the beam
   d. Mark the beam going in and out and trace around the block.
   e. Remove the block and mark the path of the beam through it.
   f. Draw in your normals and measure the critical angle. Record.
   g. The accepted index of refraction for is 1.51. From this data calculate the theoretical critical angle.
   h. Calculate the percent error compared to your measured angle from part two.

Staple all sheets together and turn in. (1 from previous day and 2 from today)
How does a Mirage work?

- The light that comes from the tree does so in all directions.
- Direct light will show the observer the true image.
- When other light is refracted it can also reach the observer.
- This is the mirage.
- When a hot surface (desert floor, asphalt road) creates a layer of very hot air it changes the refractive index. This air has a lower index of refraction and the light can refract back up to the observer.

Atmospheric refraction/reflection and the sun:
- Why does the sun pass below the horizon and we can still see it?
Dispersion

- The separation of polychromatic light into its individual components.
- Check back to refraction table. Notice they are only at 589 nm wavelengths.
- Refraction is actually dependent on the wavelength of the light wave.
- The shorter the wavelength the more it will refract. So violet light refracts the most and red light the least.
- Think back to our lab. Using a red laser should be get higher or lower numbers for critical angle?
- As you pass white light through a prism it undergoes two refractions. In each case the white light is further separated into its individual colors due to the difference in refraction.
Rainbows: The beauty of Dispersion!

- Sunlight enters a raindrop and is refracted.
- Since it is polychromatic light it also undergoes dispersion.
- The light reflects off back due to internal reflection.
- It is further refracted as it leaves the raindrop.
- Red light leaves at a $42^\circ$ angle from the original incident light.
- Violet light leaves at $40^\circ$.
- The observer sees red from raindrops higher up and violet from lower raindrops.
- Red is always on top and violet is always on bottom of a rainbow.
- Why is it an arch?
- Why can we never get the pot of gold?
Questions
   1. Where would you need to be to see a true rainbow that is a complete circle?

Sun Dogs
Sun Pillars
Thin Lenses: Must be thin!

Converging Lens: Thicker in the middle, focuses light

Diverging lens: Thicker at edges, spreads out light

Converging lens acts much like a concave mirror
Diverging lens acts much like a convex mirror.
However, we do not use the terms concave/convex lens

We can use Ray diagrams to show how images are formed from lens also.

Converging lens Ray diagrams

Diverging lens Ray diagrams
Lens Equation:  Look familiar???

Sign convention:
\( f \) is + if the lens is a converging lens (opposite side of object)
\( f \) is - if the lens is a diverging lens (same side as object)
\( q \) is + if the image is a real image (opposite side of object)
\( q \) is - if the image is a virtual image (same side as object)

Practice:
A 4.00-cm tall light bulb is placed a distance of 45.7 cm from a diverging lens having a focal length of 15.2 cm. Determine the image distance and the image size.

A 2.00-cm tall light bulb is placed a distance of 35.5 cm from a converging lens having a focal length of 12.2 cm. Determine the image distance and the image size.
Human eye: Converging lens system

Cornea: Primary focus (Fixed)
Lens: Detail focus (Adjustable)
Retina: Image produced
Optic nerve: Image sent to brain
Iris: Controls magnitude of light in
Pupil: Opening created by iris

Rods: Detect movement and low light
More sensitive than cones but not color sensitive
Cones: Detect color and bright light
3 types: Blue, Green, Red

How eye can focus both light from distant object and close object: Lens changes shape.
Myopia: Nearsighted
Eye too long or lens too strong
- diopter correction

Hyperopia: Farsighted
Eye too short or lens too weak
+ diopter correction
Chromatic Aberration

How is your sight?