LU2: LAB 1-1A: Finding the Speed of Red Light in Optical Grade Plastic

REFERENCES:

Fundamentals of Light & Lasers (OPTEC), 2nd edition
Module 1, Laboratory 1-1A, pages 33-37.
http://optecvideo.opteccrm.org, Video 1
Course 1: Fundamentals of Light and Lasers
Lab Activity Video
Choose Video #

THEORY:

The speed of light in a vacuum, *c*, is 3×10^8 m/s. In any other medium, the speed of light will be slower (The speed of light in air is the same as in a vacuum: 3×10^8 m/s). The ratio of the speed of light in the medium to the speed of light in a vacuum is the index of refraction, n, of the medium. In addition, if a ray of light enters a medium at an angle, the ray of light will bend (refract) as it changes speed. As the ray exits the medium, the speed of the light will increase again and the ray will bend back. Snell's law relates the index of refraction of the medium to how much the ray refracts.

OBJECTIVE:

Use the index of refraction and Snell's Law to determine the speed of light in optical plastic.

EQUATIONS:

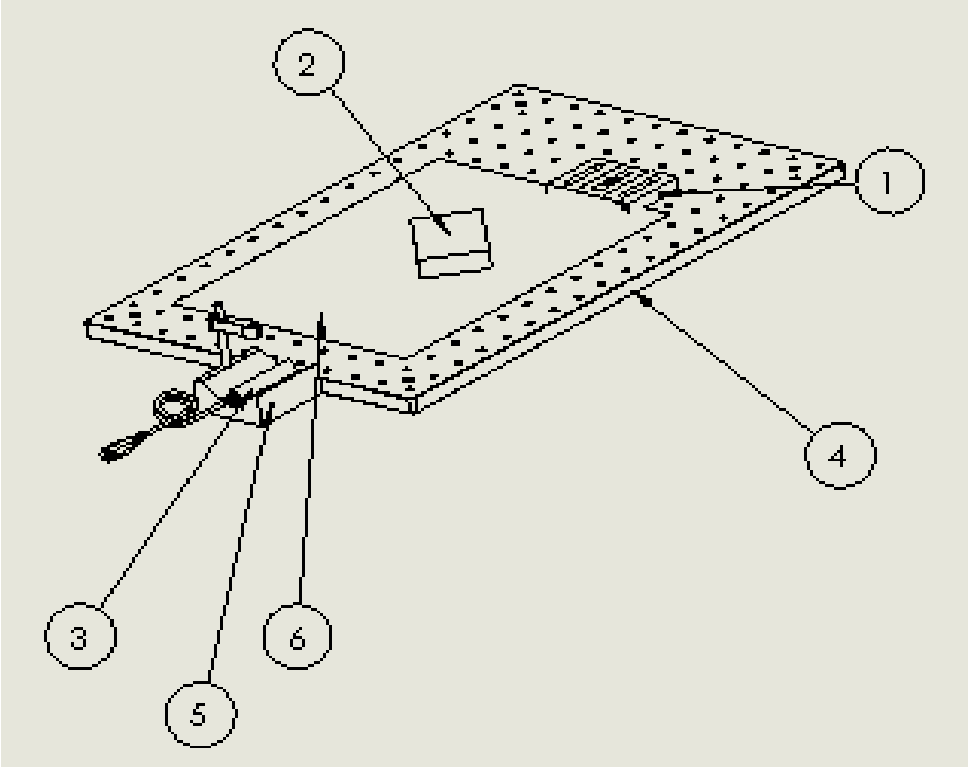
$\mathbf{n_i = c/v_i}$ (definition of index of refraction)
n_i = index of refraction of medium i
c = speed of light in a vacuum = 3×10^8 m/s
v_i = speed of light in medium i

$\mathbf{n_1 \sin \theta_1 = n_2 \sin \theta_2}$ (Snell's Law: may also be written: $n_1/n_2 = \sin \theta_2/\sin \theta_1$)
n_1 = index of refraction of the of first medium (incident ray medium)
n_2 = index of refraction of the second medium (refracted ray medium)
θ_1 = angle of incidence (angle between the incident ray & a line straight out from the surface, the normal)
θ is the Greek letter "theta"
θ_2 = angle of refraction (angle between the refracted ray in the second medium and a line straight in from the surface, the normal)

$\mathbf{n_{air} = 1}$ (The speed of light in air is considered the same as in a vacuum so $n_{air} = c/c = 1$)

EQUIPMENT:

Base, Mounting (key 1)
Block, Acrylic, rectangular (key 2)
Laser Diode Module (key 3)
Laser Diode Power Supply
Optical Breadboard (key 4)
V-Clamp, (key 5)
Protractor
8.5" x 11" sheet of white paper (key 6)
Straightedge
Misc. Hardware



SET-UP: Read the entire SET-UP & PROCEDURE, etc. and watch the VIDEO(s) before starting the lab.

1. Mount the laser diode module in the V-clamp laser mount.
2. Place the mount on the table next to the optical breadboard.
    a. Position it firmly against one of the 12" edges of the breadboard.
    b. Locate it near the midpoint so that the beam projects along the length of the breadboard near the center.
3. Position the white paper on the breadboard next to the laser so that the laser beam will project along the length of the paper near the center.
    a. Clamp the mounting base on the edge of the paper to hold it in place. Do not use tape.
4. Place a non-reflecting object at the end of the breadboard opposite the laser to contain the laser beam.
5. Take a **picture** of the set-up and **include in the Lab Write-Up**.

PROCEDURE:

1. **Always contain the laser beam. Keep direct and reflected beams away from yourself and others.**
2. Turn on the laser.
    a. Be careful not to move the laser diode/V-clamp assembly while doing this lab.
3. **Mark** the path of the laser beam on the paper.
    a. Be very detailed in **legibly marking and labeling lines and points** on the paper.
        i. A **photo** of this will be **included in the Lab Write-Up.**
    b. Use an index card to locate the beam at several points along the length of the paper.
    c. **Mark** each point and connect the marks to **trace** the beam.
4. **Label** the end of the beam path closest to the laser "O".
5. Place the acrylic block face down on the paper near the center of the paper.
    a. Position it so that the laser beam is incident on a long edge at an angle of about 40° - 50°.
    b. Position the block so that the incident point is about 10mm from the corner of the block (both long edges should intersect the beam path drawn on the paper).
6. Once #5 is done while pressing down on the block to hold it in place, **draw an outline** of it on the paper.
    a. Do not put fingerprints on the acrylic block.
7. The acrylic block will refract (cause to angle) the laser beam.
    a. The beam will exit the block offset from the original path.
    b. Use the index card to find the exiting beam and mark several points along its path to trace the beam.
8. At this point, take a **picture** of the lab and **include it in the Lab Write-Up.**
9. Turn off the laser and remove the acrylic block (remove paper from the breadboard).
10. Use a straight edge and pencil to **mark & extend** the path of the exiting beam to the outline of the acrylic block.
    a. **Label** the point of intersection (point where the beam exited the block) "B".
11. **Label** the end of the exiting beam farthest from the block "D".
12. **Label** the point where the incident beam enters the acrylic block "A"
    a. **Draw** a line to connect points A and B; this is the path of the beam in the block.
13. Use the protractor to draw a line perpendicular (90°) to the surface of the block at point A.
    a. Use a dashed line or a different color to help identify the normal line. (Place the small hole in the protractor on point A.
    b. Align the line on the protractor that goes through the hole with the edge of the block.
    c. **Place** a mark at the 90° indication on the protractor.
    d. The normal is a perpendicular line from point A to the mark.
    e. **Extend** the normal line through the outline of the block. Label the normal N_A.
14. The incident angle is the angle between line OA and normal N_A.
    a. **Draw** an arc between these lines to show the angle and label it θ_A.
15. The refracted angle is the angle between line AB and normal N_A.
    a. **Draw** an arc between these lines to show the angle and label it θ'_A (theta prime A)
16. **Measure** and **record** the incident angle, θ_A.
    a. Create a table **in the Lab Write-Up** to label and **record/log the measured angles**.
    b. Place the small hole in the protractor on point A.
    c. Align the line through the hole on the protractor with normal, N_A.
    d. Read the angle at the incident beam, OA, using the inner scale on the protractor.
    e. Extend lines if necessary.
17. **Measure** and **record** the refracted angle, θ'_A, between the refracted beam, AB, and the normal, N_A, at point A.
    a. As above, place the hole in the protractor at point A with the line through the hole aligned with the normal, N_A.
    b. Read the angle on the inner scale at the refracted beam, AB.
18. At point B, the incident beam will be inside the block (line AB); refracted beam will be the exiting beam (line BD).
    a. Repeat step 13 – 15 at point B to determine the incident angle, θ_B, and the refracted angle, θ'_B. Measure and record θ_B & θ'_B (theta prime B).
19. Take a **picture** of the white work sheet with all the angles, lines and points. **Include in Lab Write-Up**.

CALCULATIONS:

1. All calculations are **to be included in Lab Write-Up**, showing the equation and answer obtained.
    a. Answers are to be **recorded and labeled** in the 17a table in the Lab Write-Up.

2. Apply Snell's Law ($n_1 \sin \theta_1 = n_2 \sin \theta_2$) to find the index of refraction, $n_{acrylic}$, of the acrylic block at point A.
    a. At point A: the incident medium is air so $n_1 = n_{air} = 1$
    the angle of incidence, $\theta_1 = \theta_A$
    the angle of refraction, $\theta_2 = \theta'_A$
    the second medium is the acrylic block so $n_2 = n_{acrylic}$
    b. Utilizing algebra, Snell's Law can be rearranged to read $n_2 = n_1 (\sin \theta_1 / \sin \theta_2)$ so,
    $n_{acrylicA} = (1)(\sin \theta_A / \sin \theta'_A)$

3. Again using Snell's Law, recalculate the index of refraction using the angles measured at point B.
    a. At point B, the incident medium is acrylic and the second medium is air.
    b. At point B: the incident medium is the acrylic block so $n_1 = n_{acrylic}$
    the angle of incidence, $\theta_1 = \theta_B$
    the angle of refraction, $\theta_2 = \theta'_B$
    the second medium is air so $n_2 = n_{air} = 1$
    $n_{acrylicB} = n_1 = n_2(\sin \theta_2 / \sin \theta_1)$

4. Use the index of refraction definition ($n_i = c/v_i$) to **determine the speed of light** in the acrylic block.
    a. Use the average of the two values found above for $n_{acrylic}$
    b. Use algebra to rearrange the equation to get
    $v_{acrylic} = c/n_{acrylic}$

DISCUSSION:

- The index of refraction for acrylic is around 1.49
- A beam of light will bend toward the normal (angle of incidence is more than the refracted angle) when going from a lower to a higher index of refraction.
    - In this case from air to acrylic.
- It bends away from the normal when traveling from a higher to a lower index of refraction.
    - In this case from acrylic to air.
- The index of refraction for a given medium varies a little with the wavelength (color) of the incident light.
- That is why a beam of white light incident on a prism is separated into a spectrum of colors
- The speed of light in a vacuum is exactly 299,792,485 m/s.
- In air, the value is about 299,700,000.
- The index of refraction for air is about 1.0003.