General Physics Lab 8

Reflection and Refraction of Light

Objectives:

- To test the laws of reflection and refraction

Equipment:

- Semi-Circular Refraction Dish
- Water
- Laser Pointer
- Modeling Clay
- White Paper (1-2 sheets)
- Tape
- Protractor
- Ruler
- Pencil or Pen

Physical Principles:

Snell's Law of Refraction

When a light ray passes through the interface between two materials, its straight line path will bend by an amount determined by the speed of light in both materials. This "bending" of light is called refraction. Note that some fraction of the light is also reflected (see Fig. 1), with the incident angle, ϕ_1, equal to the reflected angle.

The law of refraction, known as **Snell's Law**, states the following relationship between the incident angle, ϕ_1, and the refracted angle, ϕ_2.

$$n_1 \sin(\phi_1) = n_2 \sin(\phi_2) \qquad (1)$$

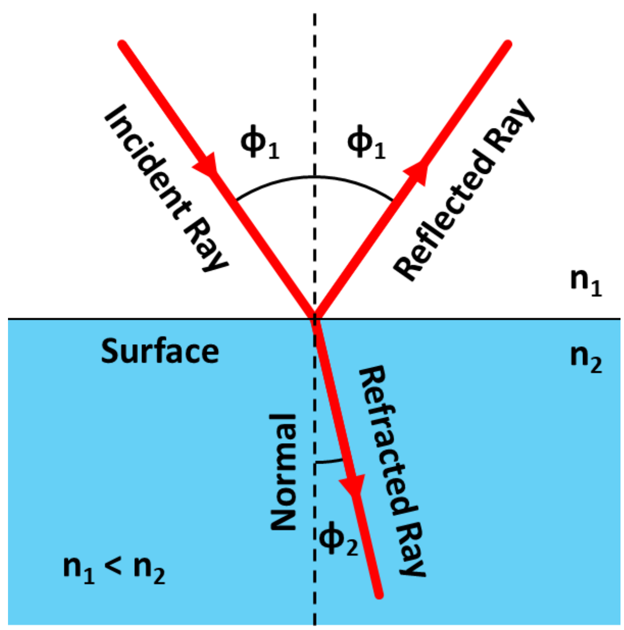

Fig. 1: A light ray incident at the interface between two media with different refractive indices can be both reflected and refracted.

The parameter n represents the index of refraction, defined as the ratio of the speed of light in a vacuum, c, to the speed of light in the material, v, i.e.,

$$n = \frac{c}{v} \;. \tag{2}$$

Therefore, the slower the speed of light in the medium is, the greater the value of n.

For example, the index of refraction for air is 1.00, and for pure water, it is 1.33. Hence, the speed of light in a vacuum is 33% greater than the speed in water.

When $n_1 < n_2$, the ray is bent <u>toward</u> the normal (perpendicular line) and $\phi_1 > \phi_2$.
On the other hand, if $n_1 > n_2$, the ray is bent <u>away</u> from the normal and $\phi_1 < \phi_2$.

Total Internal Reflection

When light passes from a medium of high index of refraction into a medium of low index of refraction ($n_1 > n_2$), a large angle of incidence can lead to **total internal reflection** as shown in Fig. 2.

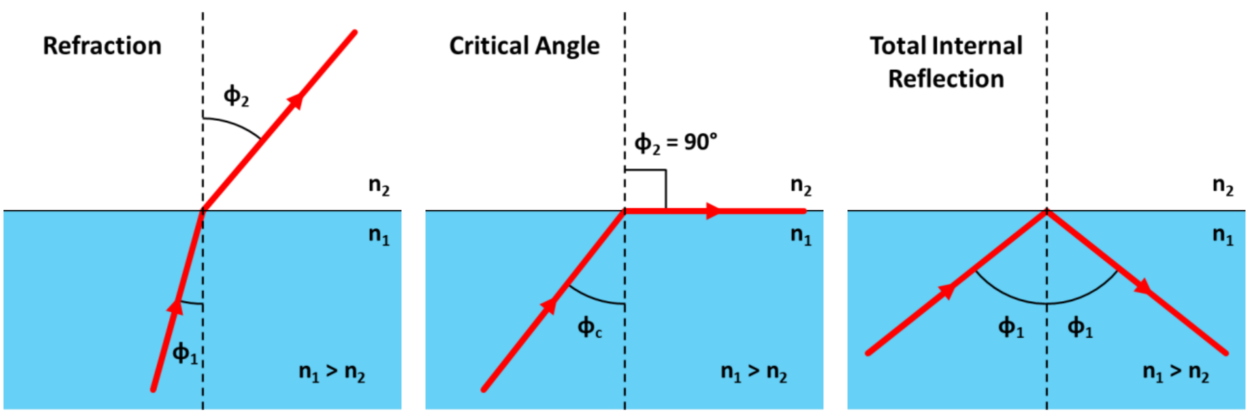

Fig. 2: For $n_1 > n_2$, total internal reflection can occur when the angle of incidence, ϕ_1, is large enough. The angle at which refraction transitions to total internal reflection is called the critical angle, ϕ_C.

For the common case of refraction <u>into</u> air ($n_2 = 1.00$), Snell's Law relates the critical angle to the index of refraction of the incident medium, n_1.

$$n_1 \sin(\phi_c) = 1 \cdot \sin(90°) \tag{3}$$

Measurement of the critical angle is one method of determining the index of refraction of a material since,

$$n_1 = \frac{1}{\sin(\phi_c)} \tag{4}$$

Procedure:

Setup

1. Draw a pair of perpendicular lines through the center of an 8.5" × 11" sheet of paper. The vertical line will represent the normal to the air/water interface. The horizontal line will represent the surface of the interface (see Fig. 3).
2. Use your protractor to draw 6 lines on the paper, representing the incident rays. Each of the incident angles (ϕ_1 = 10°, 20°, 30°, 40°, 50°, and 60°) should be measured relative to the normal, with the vertex at the intersection of the perpendicular lines.
3. Tape the paper down to the table to keep it steady during the experiment.
4. Place the water-filled semi-circular dish on the paper, and use a ruler to align the front, flat edge with the horizontal line (see Fig. 3).
5. Looking straight down into the water, use the 90° angle line of the built-in protractor to align the dish with the vertical line on the paper (see Fig. 3). After this step, you will not use the built-in protractor again (unless you need to realign the dish for the critical angle measurement).
6. Load batteries into your laser pointer.
7. Use modelling clay to form a holder for the laser pointer such that it is raised off the table and allows you to angle it (up/down) as necessary (see Fig. 4).
8. Turn off/dim the room lights (if necessary) to make it easier to see the laser light.

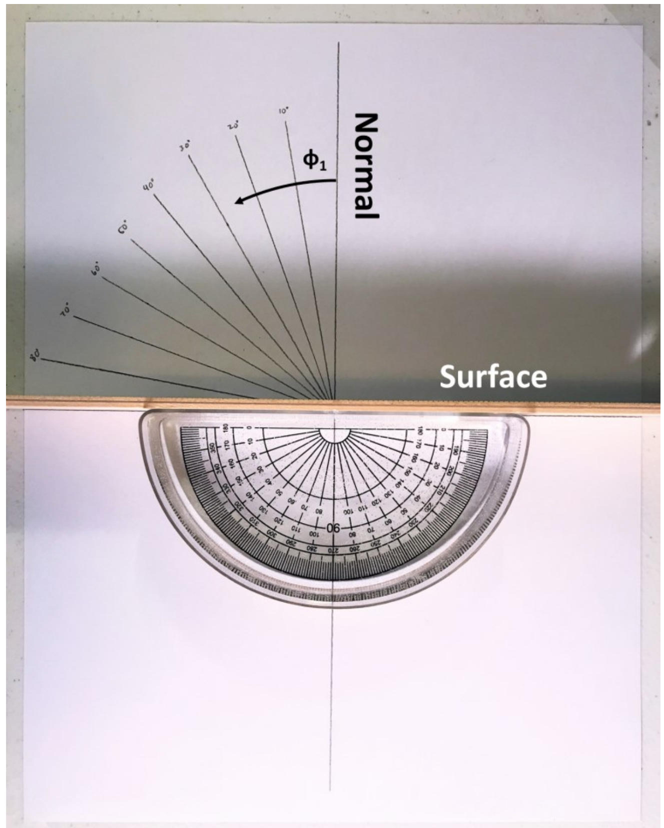

Fig. 3: Ruler is placed along the flat edge of the semi-disk to align it with the horizontal line. Built-in protractor 90° line is centered on the vertical (perpendicular) line.

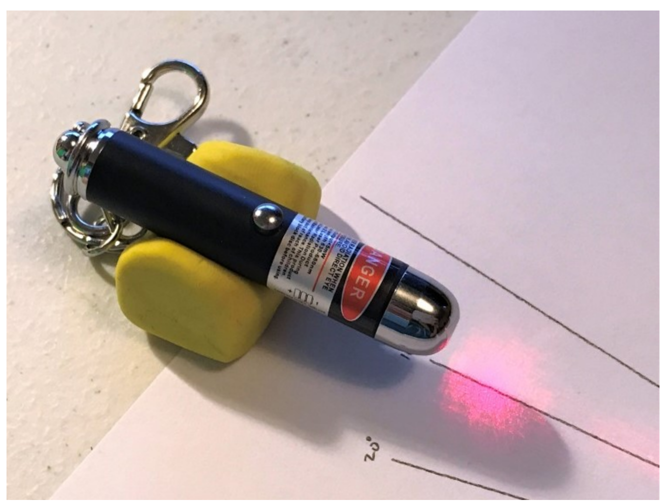

Fig. 4: Laser pointer placed on simple clay holder

WARNING: Never look directly into a laser or at its reflection from a mirror or glass surface!

Snell's Law – Light Incident from Air into Water ($n_1 < n_2$)

1. Set the laser just beyond the angle lines you have drawn so that the front of the laser pointer is over the end of the line (see Fig. 4).
2. Direct the beam toward the flat side of the semi-disk along the 10° line.
3. Adjust the angle of the pointer (up/down) so that the laser dot enters the semi-disk just above the curved, bottom surface (so that it travels through the water and not the plastic). Center the dot above the perpendicular line (see Fig. 5).

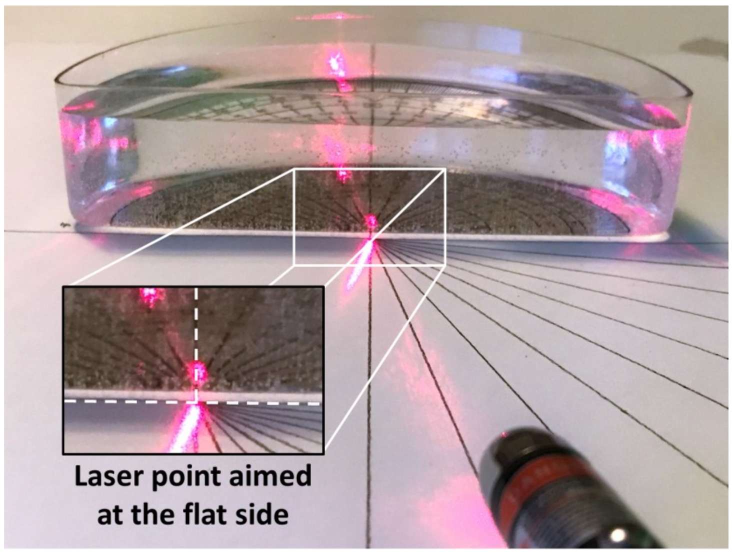

Fig. 5: Laser aimed at the side of the plastic semi-disk.

4. Adjust the position of the laser pointer side to side until you can see from above that the laser is centered over the 10° line (see Fig. 6). Make sure the dot on the glass is still centered over the perpendicular line, as in Fig. 5.

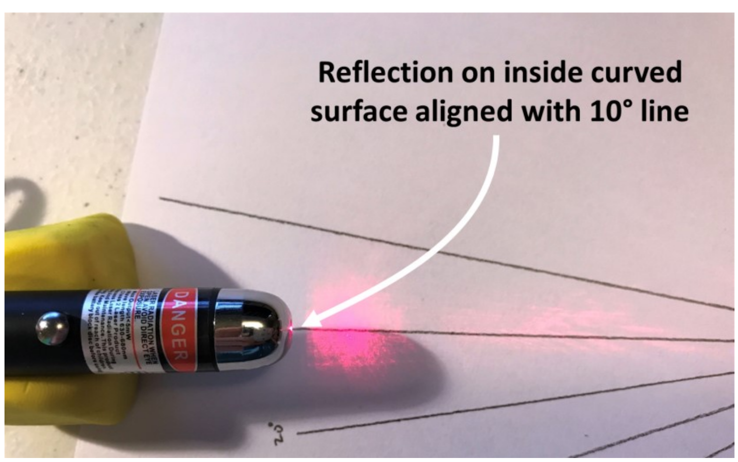

Fig. 6: Laser pointer is centered over the 10° line. You can see that the reflection on the inside edge of the pointer hole is centered over the line.

5. Check to see that the refracted ray exits the semi-disk perpendicularly to the curved surface and makes a line on the paper (see Fig. 7).

   If you do not see a laser line on the paper, you may need to adjust the angle of the laser up/down so that it exits the semi-disk close to the bottom of the dish (above the curved, bottom surface) and skims across the paper, making a line.

6. Mark a point on the paper where the laser forms a visible line. Later, you will draw a line connecting this point back to the perpendicular intersection point, indicating the path of the refracted light ray.

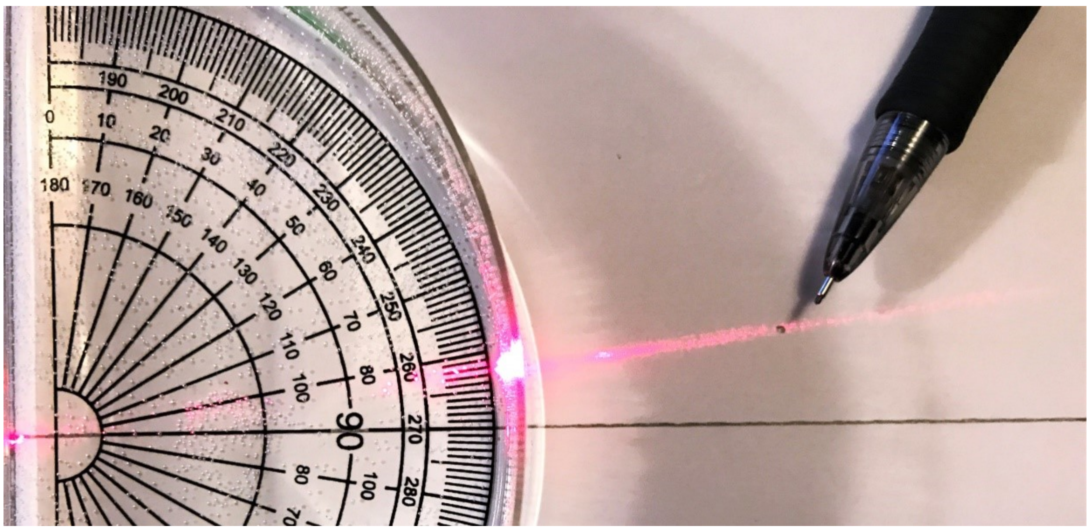

Fig. 7: Laser light exiting the semi-disk and making a line on the paper.
A pencil is used to mark a point on that line.

7. Repeat this process for each incident angle, recording the incident angle, ϕ_1, and marking a point for the refracted angle, ϕ_2 (see Fig. 8 and Fig. 9).

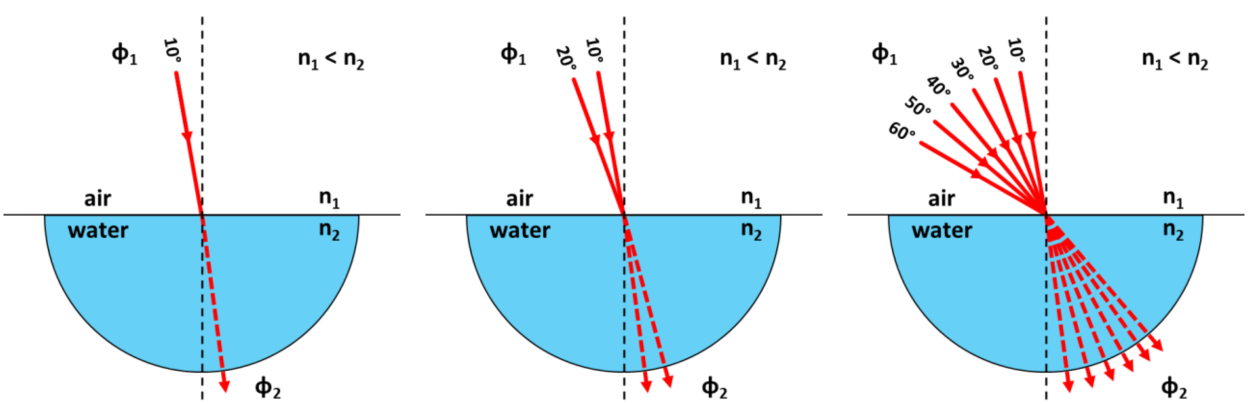

Fig. 8: Laser light enters the semi-disk from air at various incident angles, ϕ_1, refracts at the air/water interface, and travels through the water at the refracted angles, ϕ_2.

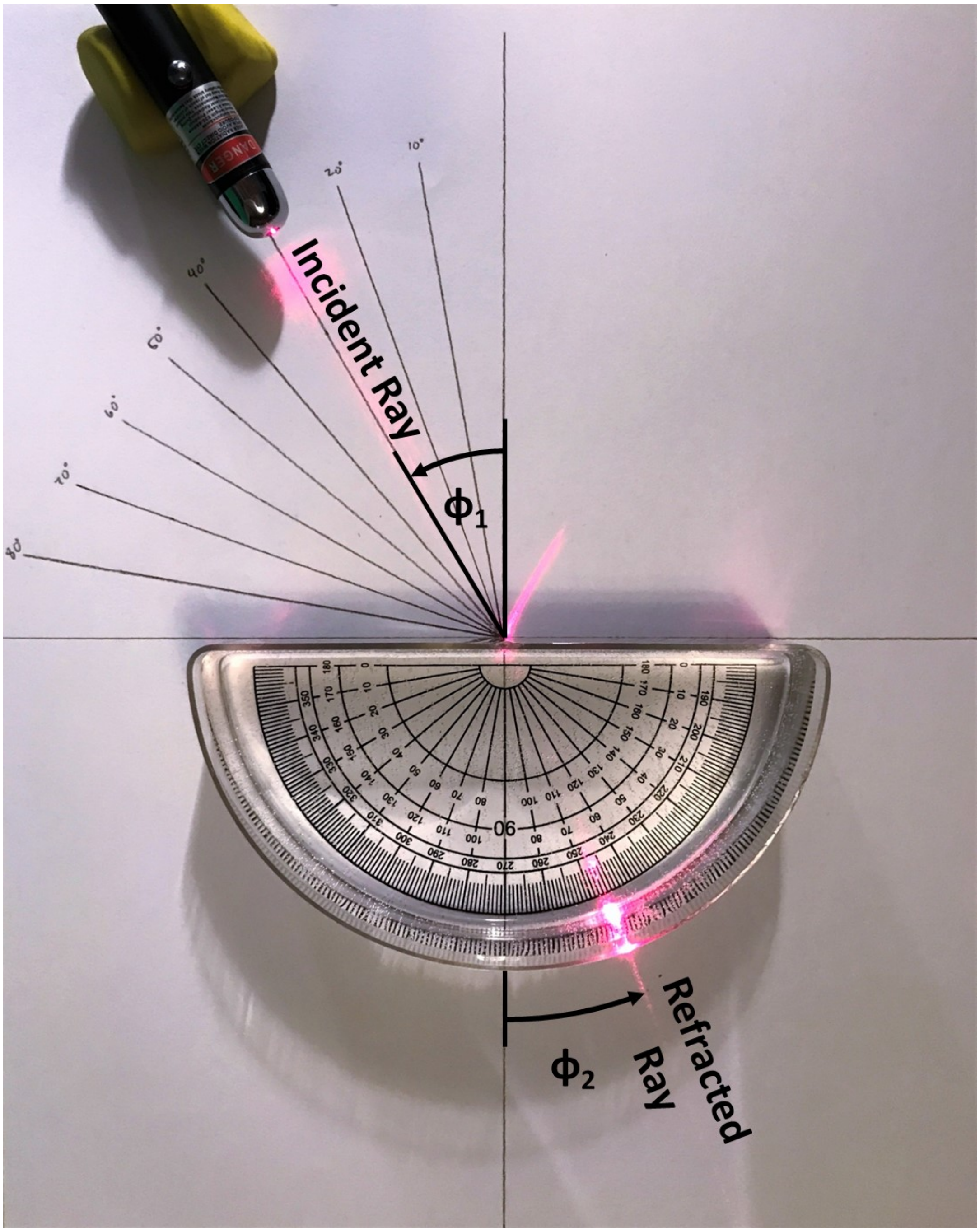

Fig. 9: Laser light enters the semi-disk from air, refracts at the air/water interface, travels through the water, exits the semi-disk perpendicular to the curved surface, and makes a visible line on the paper.

8. After marking a point for each refracted ray, move the semi-disk to the side and draw lines from the marks you made back to the origin (intersection point).
9. Use a protractor to measure and record the refracted angles, ϕ_2, relative to the perpendicular (normal) line.

Critical Angle – Light Incident from Water into Air ($n_1 > n_2$)

1. Reverse the situation by shining the laser through the curved circular side of the semi-disk such that it emerges from the water into air on the flat side at the intersection point of the perpendicular lines (see Fig. 10).
2. Adjust the angle of the incident laser beam until the emerging ray just skims along the air-water interface, transitioning to total internal reflection (see Fig 11).
3. Mark the incident ray with a pencil (estimate the center of the beam – see Fig. 11b), remove the semi-disk, and trace the ray back to the intersection point as before.
4. Use a protractor to measure and record the incident (critical) angle, ϕ_c, relative to the perpendicular (normal) line.

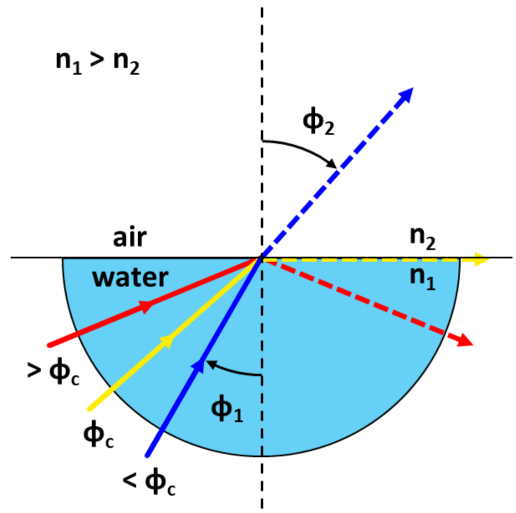

Fig. 10: Light emerges from water into air until the angle is greater than the critical angle at which point the light undergoes total internal reflection.

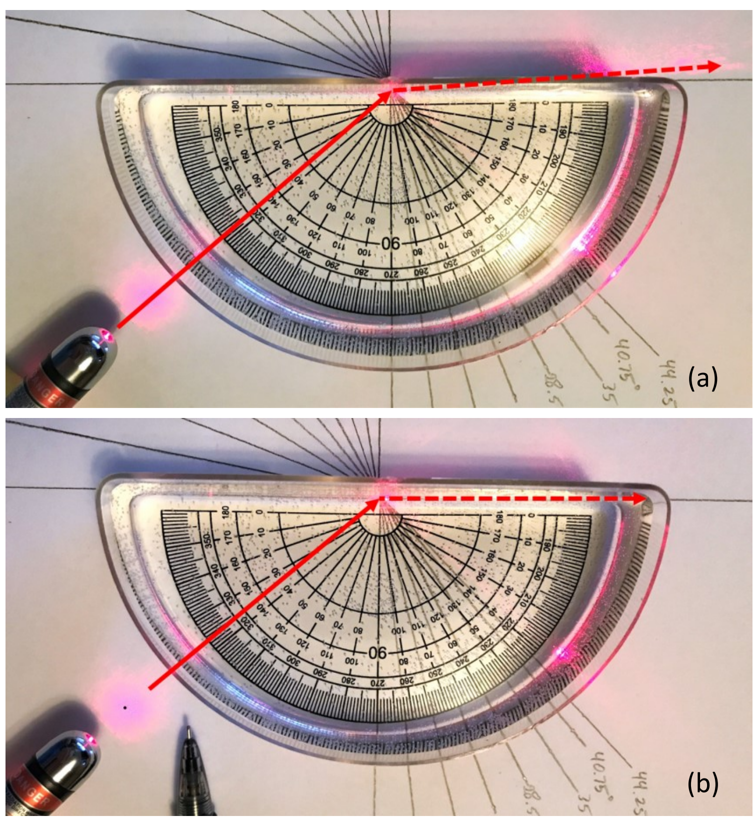

Fig. 11: (a) Laser shining at just greater than the critical angle.
(b) Laser shining at the critical angle. Pencil used to mark the incident ray.

Analysis:

Snell's Law ($n_1 < n_2$)

For light refracting from air into water, Eq. (1) becomes,

$$1 \cdot \sin(\phi_1) = n_2 \sin(\phi_2) \qquad (5)$$

This suggests that a plot of $\sin(\phi_1)$ vs. $\sin(\phi_2)$ will be linear with a slope of n_2.

1. Generate a plot of $\sin(\phi_1)$ (y-axis) vs. $\sin(\phi_2)$ (x-axis) and include the point (0,0), corresponding to a 0° incident angle and 0° refracted angle.

   Note: Be careful if you use programs such as Google Sheets or Excel to compute the sine of angles, as they will assume the angles are in radians. In Google Sheets and Excel, you can use the RADIANS( ) function to convert from degrees to radians.

2. Perform a linear fit to determine the slope of the line. The slope is your measured value for the index of refraction of water.
3. Compare your slope with the accepted index of refraction of water, $n_{water} = 1.33$, by computing the percent error.

$$\%Error = \frac{|n_{water} - slope|}{n_{water}} \times 100\%$$

Critical Angle ($n_1 > n_2$)

1. Use your critical angle measurement, along with Eq. (4), to determine the index of refraction of water, n_c.
2. Compare n_c with $n_{water} = 1.33$ by computing the percent error.

$$\%Error = \frac{|n_{water} - n_c|}{n_{water}} \times 100\%$$