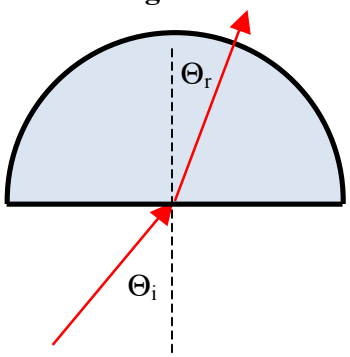
Snell's Law

A physics class was attempting to determine the relationship between the angle of incidence (Θ_i) and the angle of refraction (Θ_r) for light traveling from one material to another.

Experiment 1

The class divided up into 10 different groups of three students each. The activity involved shining laser light from air into a dish of water at a known angle of incidence and measuring the angle of refraction in the water. **Figure 1** represents the experimental set-up. Each lab group was assigned a set of angles of incidence; their goal was to measure the corresponding angles of refraction. Results from each lab group were collected to provide measurements at 1-degree intervals for angles of incidence between 0° and 90°.

Figure 1

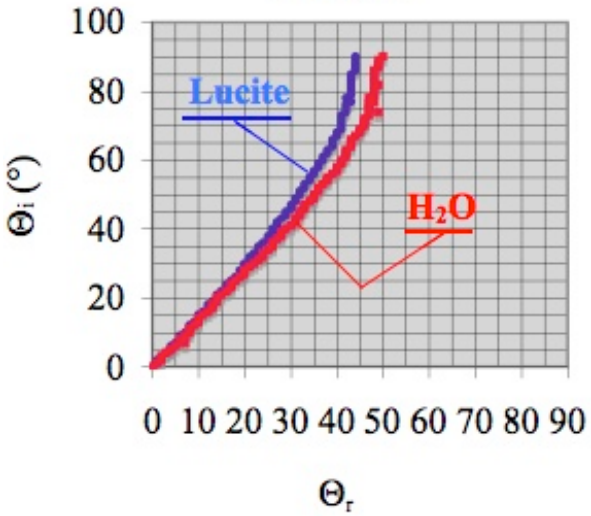


Experiment 2

Once the class completed their measurements using a water-filled dish, they repeated the investigation using a D-shaped, solid disk of Lucite glass. They made similar measurements of Θ_i and Θ_r and gathered results from the entire class.

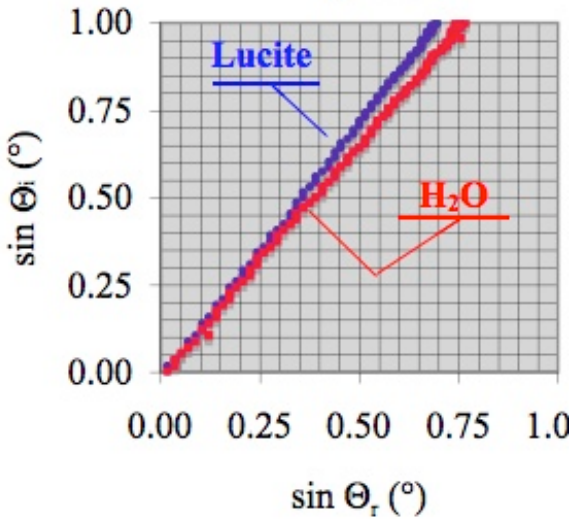
The class data was plotted using a computer program. Two types of plots were created for both experiments. The plot shown in **Figure 2** included the angles of refraction and incidence along the vertical and horizontal axes, respectively. The plot shown in **Figure 3** included the sines of these angles along the two axes. A method known as *linear regression* was used to determine the slopes of the line and to judge how closely the plotted data fit a line of the form $y = m \bullet x + b$. The slopes (m) of each line on both graphs are shown below each graph.

Figure 2



Water: m = 1.69
Lucite: m = 1.88

Figure 3



Water: m = 1.35
Lucite: m = 1.47

Questions:

1. Which statement describes the purpose of these two experiments?
   a. To observe how light refracts.
   b. To determine the direction that light refracts.
   c. To measure the angles of incidence and refraction for light bending at a boundary.
   d. To determine the mathematical relation between the angle of incidence and refraction.

2. Which angle is largest in **Figure 1**?
   a. The angle of incidence (Θ_i)
   b. The angle of refraction (Θ_r)
   c. They are the same measure.
   d. It is impossible to tell.

3. For the same angle of incidence, in which material - water or Lucite - is the angle of refraction the greatest?
   a. The Θ_r value is greatest in water.
   b. The Θ_r value is greatest in Lucite.
   c. They have the same measure.
   d. It is impossible to tell.

4. How do changes in the angle of incidence affect the angle of refraction?
   a. Increasing the angle of incidence increases the angle of refraction.
   b. Increasing the angle of incidence decreases the angle of refraction.
   c. Increasing the angle of incidence has no affect upon the angle of refraction.
   d. Increasing the angle of incidence first increases and then decreases the angle of refraction.

5. An **index of refraction** value is an indicator of the speed at which light travels within a material. Every material has a unique index of refraction value. Index of refraction (n) values are shown in the table at the right. Based on the data in **Figure 2**, how does an increase in the index of refraction affect the amount of refraction at a boundary?

Material	n
Air	1.00
Water	1.33
Lucite	1.45

   a. There is more refraction for smaller n values.
   b. There is more refraction for larger n values.
   c. The value of n seems to have no affect upon the amount of refraction.
   d. This information does not allow one to determine the affect of the n value on the amount of refraction.

6. An **index of refraction** value is an indicator of the speed at which light travels within a material. Every material has a unique index of refraction value. Index of refraction (n) values are shown in the table at the right. When light is passes from air into another material, what combination of angle of incidence (Θ_i) and index of refraction value (n) would result in the greatest angle of refraction?

Material	n
Air	1.00
Water	1.33
Lucite	1.45

   a. A large $\mathbf{\Theta_i}$ and a large **n** value.
   b. A small $\mathbf{\Theta_i}$ and a small **n** value.
   c. A small $\mathbf{\Theta_i}$ and a large **n** value.
   d. A large $\mathbf{\Theta_i}$ and a small **n** value.

7. How are the results of **Experiment 2** different than the result of **Experiment 1**?
   a. The data reveal an entirely different refraction law.
   b. The lines on both graphs have an entirely different shape.
   c. There seems to be less refraction occurring, leading to smaller slope values.
   d. There seems to be more refraction occurring, leading to larger slope values.

8. How are the graphs in **Figure 1** different than the graphs in **Figure 2**?
   a. The graphs use different angle values.
   b. There is more error in the graphs of **Figure 2**.
   c. The **Figure 1** graphs are not linear; the **Figure 2** graphs are linear.
   d. The **Figure 2** graphs are for water; the **Figure 3** graphs are for Lucite.

9. How might the students' conclusions be different if they collected data for small angles of incidence - such as between 0° and 40°?
   a. There would not likely be any change in their conclusion.
   b. They would have observed a slope that was greater than 1.0.
   c. They would have observed a much smaller slope for these smaller angles.
   d. They might have concluded that **Figure 2** would be the graph having a linear relationship.

10. An **index of refraction** value is an indicator of the speed at which light travels within a material. Every material has a unique index of refraction value. Index of refraction (n) and speed of light (v) values are shown below.

Material	n	v (m/s)
Air	1.00	3.00×10^8
Water	1.33	2.26×10^8
Lucite	1.45	2.07×10^8

Scientists know that the slope of any line on the sine graph for these experiments is related to the ratio of the speed of light values of the two materials through which light travels. Which equation seems to best fit the data in **Experiment 1**?

a. $\Theta_i / \Theta_r = v_{water} / v_{air}$
b. $\sin \Theta_i / \sin \Theta_r = v_{water} / v_{air}$
c. $\Theta_i / \Theta_r = v_{air} / v_{water}$
d. $\sin \Theta_i / \sin \Theta_r = v_{air} / v_{water}$

11. An **index of refraction** value is an indicator of the speed at which light travels within a material. Every material has a unique index of refraction value. Index of refraction (n) values are shown in the table at the right. Scientists know that the slope of any line on the sine graph for these experiments is related to the ratio of the index of refraction values for the two materials. Based on this knowledge, how would the **Figure 3** graph appear if these experiments were repeated for light traveling from air into ice?

Material	n
Air	1.00
Ice	1.31
Water	1.33
Ethanol	1.36
Lucite	1.45
Flint glass	1.65

   a. The **Figure 3** graph would be more curved than it is for water and Lucite.
   b. The line on the **Figure 3** graph would be positioned below the water line.
   c. The line on the **Figure 3** graph would be positioned above the Lucite line.
   d. The line on the graph would be positioned between the water and the Lucite lines.