Bending Light – ID: 8878

By Peter Fox

Time required
45 minutes

Activity Overview

In this activity, students explore the refraction of a single light ray. They begin by exploring light traveling from a less dense medium into a denser medium. They use a numerical approach to establish a relationship between the angle of incidence and the angle of refraction. Then, students explore refraction when the light ray travels from the denser medium to the less dense medium. Students check to see if their relationship still holds and determine the critical angle.

Concepts

- *Refraction of light*
- *Snell's law*
- *Refractive index and critical angle*

Materials

To complete this activity, each student will require the following:

- *TI-Nspire™ technology*
- *pen or pencil*
- *blank sheet of paper*

TI-Nspire Applications

Graphs & Geometry, Lists & Spreadsheet, Data & Statistics, Notes

Teacher Preparation

This activity assumes students already have a reasonable understanding of light rays, reflection, conventions for measuring angles in physics (measured to the normal), and numerical approaches used to help establish relationships between two variables.

- *Because the TI-Nspire document is a simulation, it is important for students to see real examples of refraction. Therefore, it is recommended that you provide students with a real-world example of refraction, such as a drinking straw in a glass of water.*
- *The screenshots on pages 2–9 demonstrate expected student results. Refer to the screenshots on pages 10–12 for a preview of the student TI-Nspire document (.tns file).*
- ***To download the .tns file, go to education.ti.com/exchange and enter "8878" in the search box.***

Classroom Management

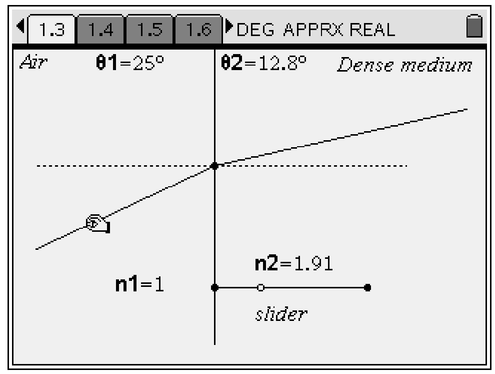
- *This activity is designed to be **teacher-led** with students following along on their handhelds. You may use the following pages to present the material to the class and encourage discussion. Note that the majority of the ideas and concepts are presented only in **this** document, so you should make sure to cover all the material necessary for students to comprehend the concepts.*
- *Students may answer the questions posed in the .tns file using the Notes application or on blank paper.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration in this activity:

- What causes light to bend as it travels from one medium to another?
- What affects the amount of bending?
- What is the critical angle?

Students will carry out the activity using simulated refraction. They will first explore refraction by moving the incident light ray and making observations of the refracted ray. Then, they will measure a series of incident and refracted angles with a view to establishing a relationship between the angle of incidence and the angle of refraction.

Problem 1 – Qualitative study of refraction

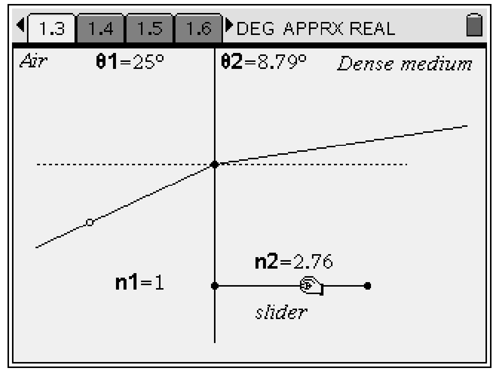


Step 1: Students should open the file **PhyAct14_bendinglight_EN.tns** and read the first two pages. Page 1.3 is a simulation of an incident light ray and the resulting refracted ray. Students should drag the incident light ray around the *Air* medium and observe what happens to the light ray as it passes through to the *Dense medium*. Then, students should answer question 1 on page 1.4. Note: In this and subsequent problems, variables are defined as follows: **n1** is the index of refraction for the less-dense medium; **n2** is the index of refraction for the denser medium; **θ1** is the angle between the light ray and the normal in the less-dense medium; and **θ2** is the angle between the light ray and the normal in the denser medium.

Q1. Describe what happens to the light ray as it passes from air into the dense medium.

A. *The light ray bends as it travels from the air into a denser medium. More specifically, the light bends toward the normal. Increasing the incident angle makes the bending more noticeable.*

Step 2: Next, students should adjust the refractive index of the dense medium (**n2**) by moving the slider on page 1.3. Then, they should answer questions 2 and 3 on pages 1.4 and 1.5. Note: Do not allow students to modify the last *Calculator* page and last *Lists & Spreadsheet* page in this or subsequent problems. The *Calculator* page defines a function that is being used to calculate the refraction. The *Lists & Spreadsheet* page is being used to graph appropriate points that respond to the movement of the incident light ray. Changing either of these pages may result in erroneous results.

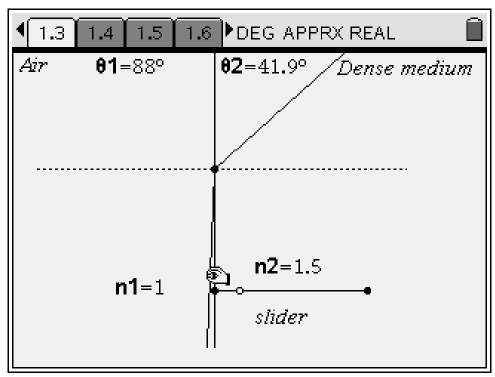


Q2. How does changing the refractive index affect the refracted light ray?

A. *As the refractive index is increased, the amount of refraction increases. As the refractive index is decreased, the amount of refraction decreases.*

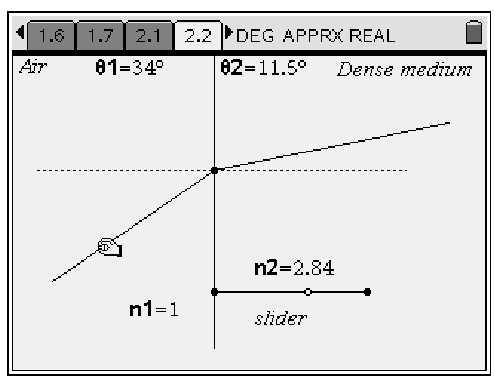
Q3. If **n2** is set at 1.5, what is the largest possible value for **θ2**, the angle of refraction? What value of **θ1**, the angle of incidence, leads to this angle?

A. *The largest angle for **θ2** is approximately 41.9°. This is obtained when **θ1** is as close to 90° as possible.*

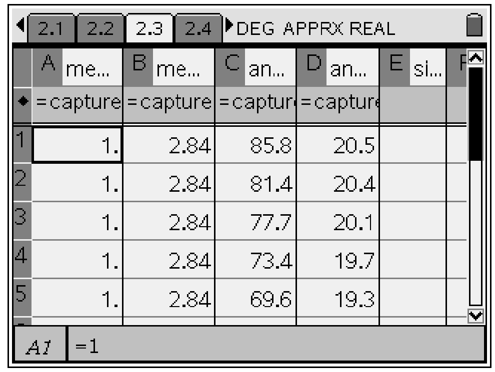


Problem 2 – The relationship between angle of incidence and angle of refraction

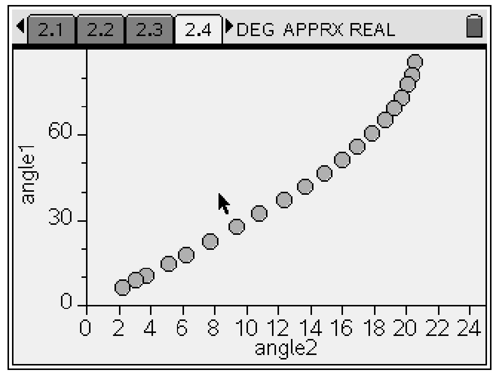
Step 1: Next, students should move to page 2.1 and read the text there. Page 2.2 contains a refraction diagram similar to the first problem. This time, however, **n1**, **n2**, **θ1,** and **θ2** are linked to the *Lists & Spreadsheet* application on page 2.3 and the *Data & Statistics* application on page 2.4.



Step 2: Students should again drag the incident ray around the *Air* medium. They should use manual data capture to record the values of **n1**, **n2**, **θ1**, and **θ2** as they move the incident ray around. To record a data point, students should press ctrl . . They should not adjust the refractive index of the dense medium (**n2**). You may wish to assign students specific values of **n2** to test, and then have the class compare their results. Students should collect at least 20 data points for a wide range of incident angles.



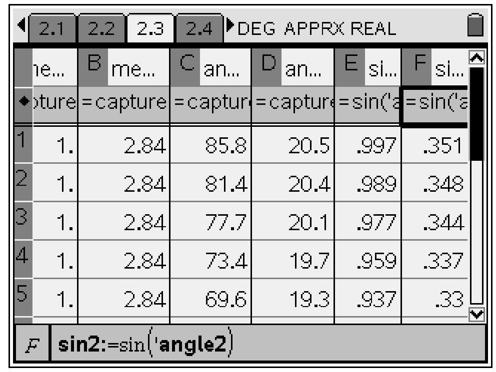
Step 3: Students should next examine the scatter plot of **angle1** vs. **angle2** on page 2.4. Then, they should answer question 4 on page 2.5.



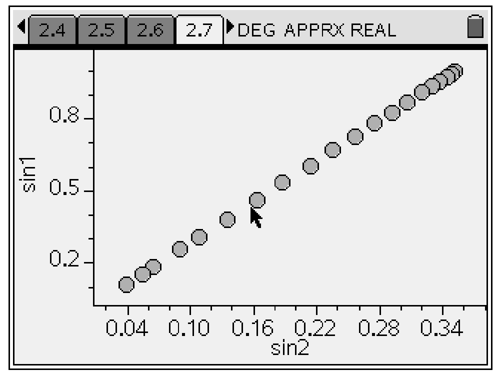
Q4. Is the relationship between the angle of incidence (**angle1**) and the angle of refraction (**angle2**) linear?

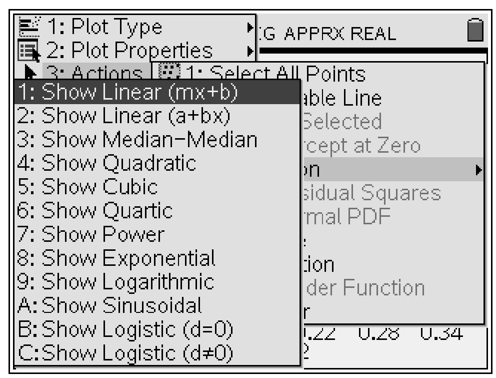
A. *If data are collected over only a small range of angles, the relationship may appear approximately linear to some students. Students should be encouraged to select a range of measurements to get a sense of what is happening. Remind students that **angle1** is the variable storing values of **θ1** and **angle2** is the variable storing values of **θ2**. This will help them connect the graph to the simulation.*

Step 4: Next, students should use formulas in Columns E and F of the spreadsheet on page 2.3 to calculate sin(**angle1**) and sin(**angle2**), respectively.



Step 5: Next, students should plot **sin1** vs. **sin2** on the *Data & Statistics* application on page 2.7. They should use the **Regression** tool (**Menu > Actions > Regression > Show Linear (mx + b)**) to find the equation of the best-fit line for the data. They should then answer questions 5–7 on pages 2.8 and 2.9.



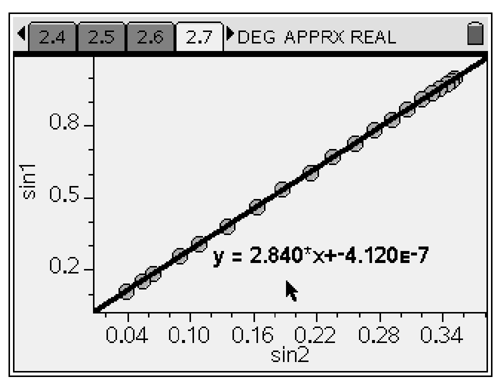


Q5. What does the shape of the graph of **sin1** vs. **sin2** indicate about the relationship between angle of incidence and angle of refraction?

A. *The graph is linear. Therefore, the ratio of **sin1** to **sin2** must be a constant. Encourage students who used different values of **n2** to compare their results. They should all obtain linear graphs. From these data, they should conclude that the ratio of **sin1** to **sin2** is always a constant for a given value of **n2**.*

Q6. What is the equation for the best-fit line for **sin1** vs. **sin2**?

A. *The equation for the line will vary depending on the values of **n2** students have chosen. The slope of the line should be equal to **n2**.*

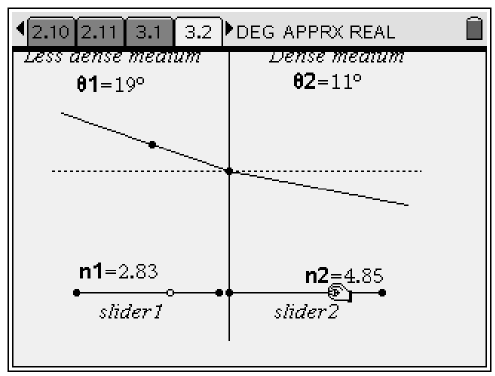


Q7. What does this equation indicate about the relationship between refractive index, angle of incidence, and angle of refraction?

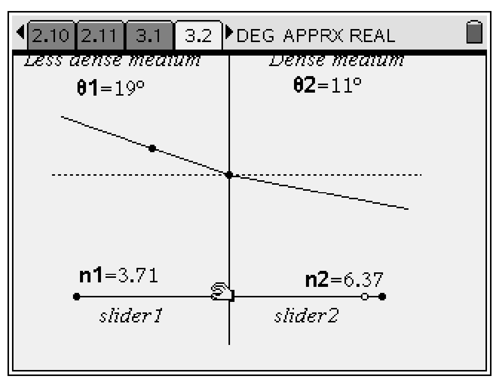
A. *The slope of the line is equal to **n2**. This indicates that, for this particular setup, the ratio of **sin1** to **sin2** is equal to the refractive index of the denser medium. As a connection to the next problem, have students identify the value of **n1**. They should note that **n1** = 1. Encourage them to hypothesize about the effects of varying both **n1** and **n2** on the angle of refraction. In the next problem, they will be able to test their hypotheses.*

Problem 3 – Effect of refractive index on refraction

Step 1: Students should now move to page 3.1 and read the instructions there. Page 3.2 contains a refraction diagram similar to the first problem. This time, however, both **n1** and **n2** are variable. The sliders have been set such that **n2** is always larger than **n1**.

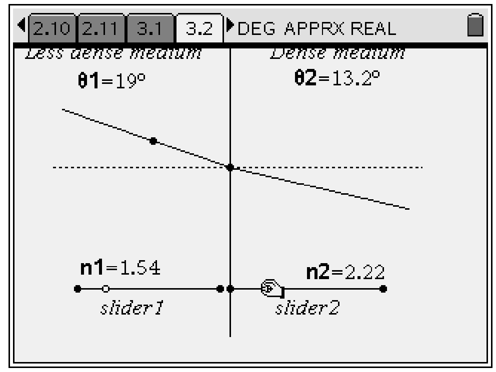


Step 2: Students should change the values of **n1** and **n2** using the sliders. They should use manual data capture to record the values of **n1**, **n2**, **θ1**, and **θ2** as they adjust the sliders. They should not adjust the angle of incidence while performing data collection. You may wish to assign students specific values of **θ1** to test, and then have the class compare their results. Students should collect at least 20 data points for a wide range of refractive indexes. Then, they should answer question 8 on page 3.3.

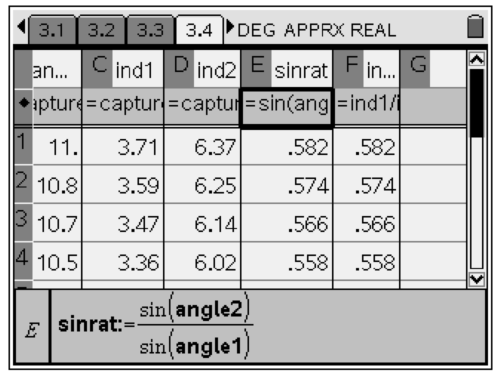


Q8. How does the relationship between **n1** and **n2** affect the amount of bending?

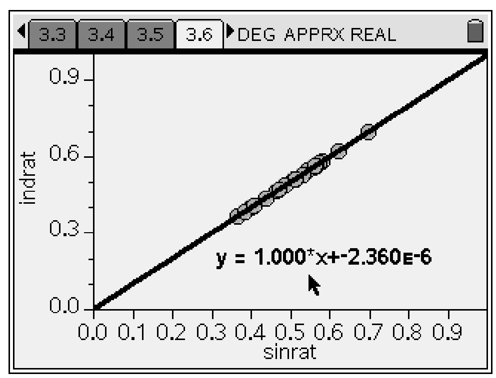
A. *The ratio between **n1** and **n2** determines the amount of bending. When **n1** and **n2** are similar, very little bending occurs. When the ratio between **n1** and **n2** is large, a significant amount of bending occurs.*



Step 3: The *Lists & Spreadsheet* application on page 3.4 contains formulas in Columns E and F. Column E contains the ratio of sin(**angle2**) to sin(**angle1**). This ratio is assigned to the variable **sinrat**. Column F contains the ratio of **n1** to **n2**. This ratio is assigned to the variable **indrat**. Initially, these columns may not contain any data. For each column, students should highlight the formula bar and press [enter] twice to force the TI-Nspire to calculate the value. Students should then examine the values in Columns E and F and discuss their observations.



Step 4: Next, students should use the *Data & Statistics* application on page 3.6 to plot **indrat** vs. **sinrat**. They should use the **Regression** tool to find the equation of the best-fit line for the data. Then, they should answer questions 9 and 10 on page 3.7.



Q9. What is the equation for the line relating **sinrat** to **indrat**?

A. *Students should obtain an equation very close to **sinrat** = **indrat**.*

Q10. Use this information to write a general equation relating the indexes of refraction of two media to the sines of the angles of incidence and refraction.

A. *The general equation relating refractive indexes and the sines of the angles of incidence and refraction is the following:*

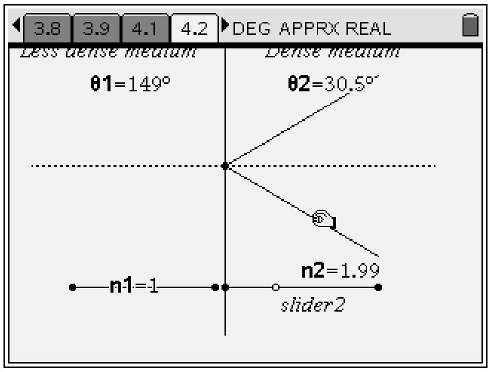
$$n_1 sin(\theta_1) = n_2 sin(\theta_2), \text{ or}$$

$$\frac{n_1}{n_2} = \frac{sin(\theta_2)}{sin(\theta_1)}$$

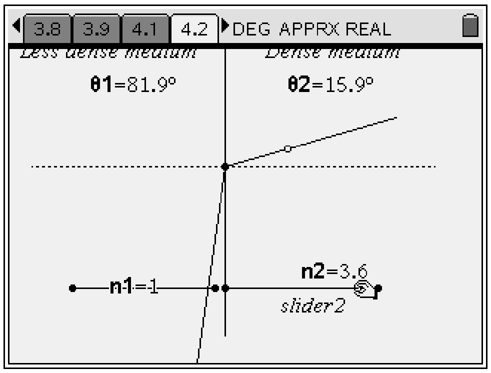
where θ_1 is the angle of incidence and θ_2 is the angle of refraction. This equation is known as Snell's law. Remind students that, in problem 2, ***n1*** *was set equal to 1, so the ratio of* ***n2*** *to* ***n1*** *was always equal to* ***n2****.*

Problem 4 – The critical angle and total internal reflection

Step 1: Next, students should move to page 4.1 and read the text there. Page 4.2 contains a refraction diagram similar to the first problem. This time, however, the incident light ray is in the denser medium (*Dense medium*). In this simulation, **n1** is fixed at 1, but **n2** can be adjusted.



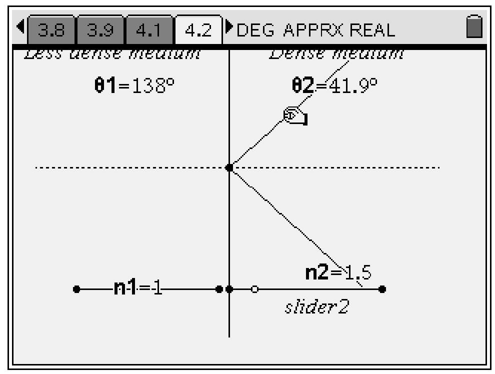
Step 2: Students should explore the simulation by moving the incident ray and adjusting the refractive index of the denser medium. Then, they should answer questions 11–14 on pages 4.3–4.4.



Q11. Why does the refracted light ray bend farther away from the normal than the incident light ray?

A. *The amount a light ray bends depends on its change in speed when it enters the new medium. If it slows down, it bends toward the normal. If it speeds up, it bends away from the normal. The situation on page 4.2 is the reverse of the original situation. Because the light ray is moving from a denser medium to a less-dense medium, it speeds up and bends away from the normal.*

Q12. For **n1** = 1.0 and **n2** = 1.5, what is the critical angle? That is, at what angle of incidence does the light get reflected back into the denser medium?



A. *Internal reflection occurs when the angle of incidence is greater than approximately 41.8°. You may wish to follow up this activity with a formal discussion of how the critical angle is calculated. This exercise, however, determines the critical angle reasonably accurately.*

Q13. How does changing **n2** affect the critical angle?

A. *As **n2** increases, the critical angle decreases. As **n2** decreases, the critical angle increases.*

Q14. Does the relationship between **n1**, **n2**, **θ1**, and **θ2** that you determined in problem 3 hold for situations in which the incident light ray is in the denser medium? Show your work.

A. *To test Snell's law in this case, students should select values for **n2** and **θ2** and record the value of **θ1** (in this simulation, **n1** is set equal to 1). Then, they should substitute these values into the Snell's law equation and test for equality. For **n2** = 2.02 and **θ2** = 14.8º, **θ1** = 31.2º. A calculation based on Snell's law yields the following:*

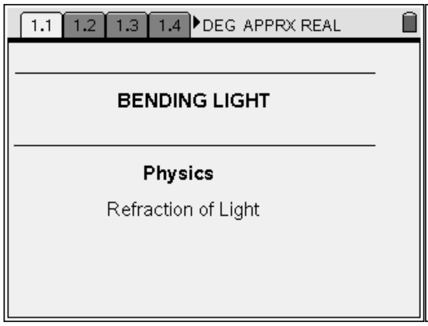
$$\frac{n2}{n1} = \frac{2.02}{1} = 2.02$$

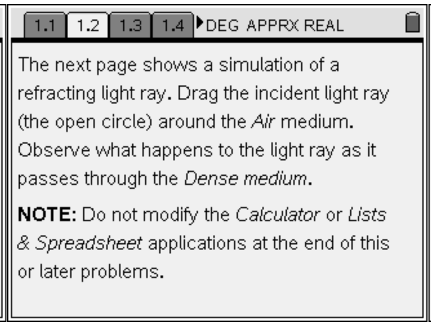
$$\frac{\sin(\theta 1)}{\sin(\theta 2)} = \frac{\sin(31.2^\circ)}{\sin(14.8^\circ)} = \frac{0.518}{0.255} = 2.03$$

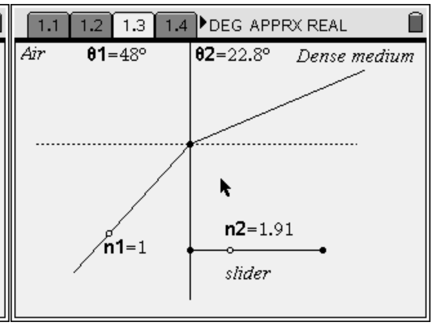
These values are equal within the precision of the simulation, so Snell's law is confirmed.

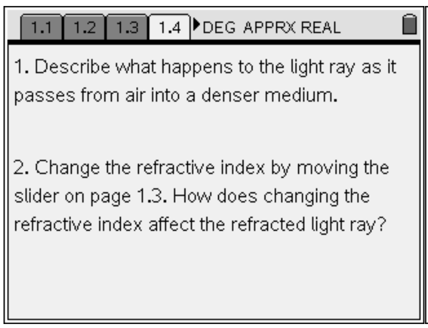
Bending Light – ID: 8878

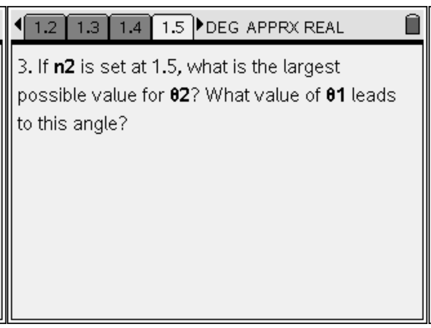
(Student)TI-Nspire File: *PhyAct14_bendinglight_EN.tns*

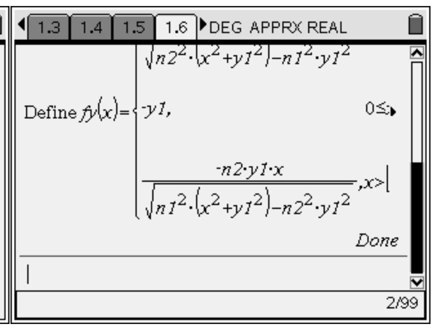


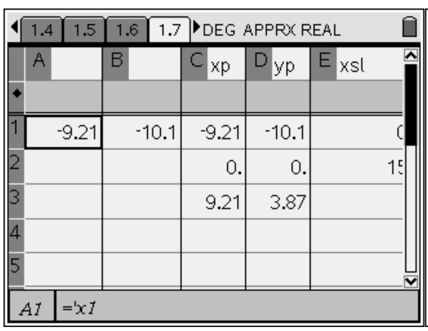


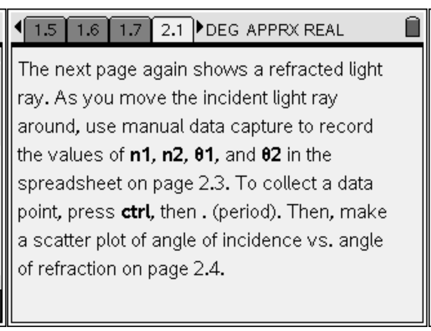


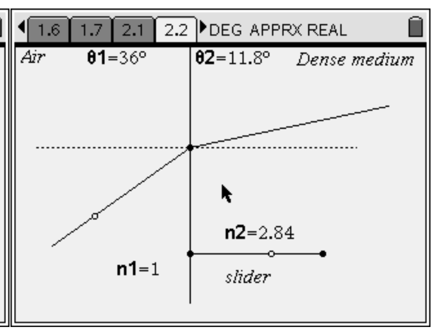


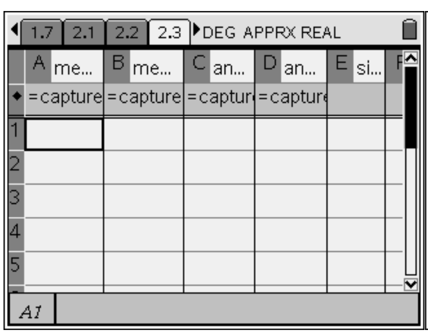


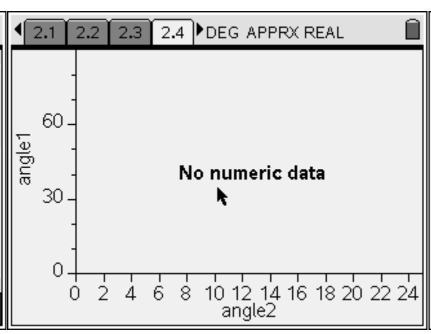


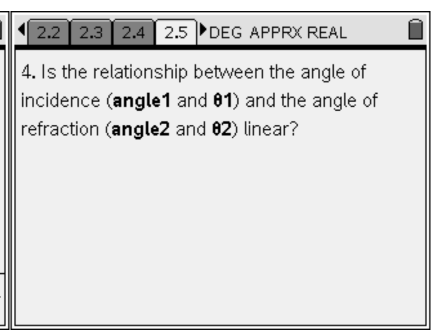




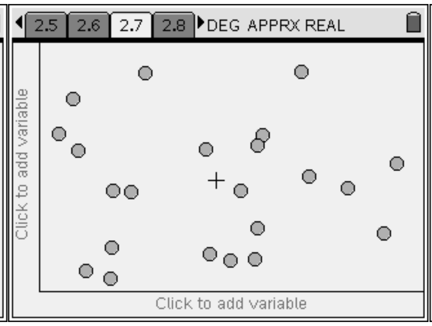








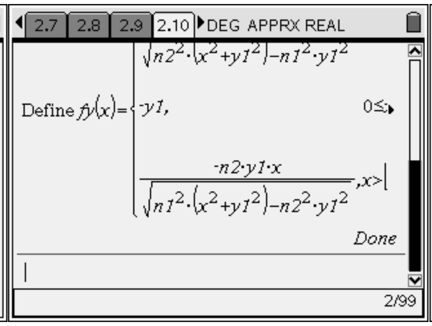
Use formulas to calculate sin(**angle1**) and sin(**angle2**) in columns E and F, respectively, of the spreadsheet on page 2.3. Then, make a scatter plot of **sin1** vs. **sin2** on page 2.7.



5. What does the shape of the graph of **sin1** vs. **sin2** indicate about the relationship between angle of incidence and angle of refraction?

6. What is the equation for the best-fit line for **sin1** vs. **sin2**?

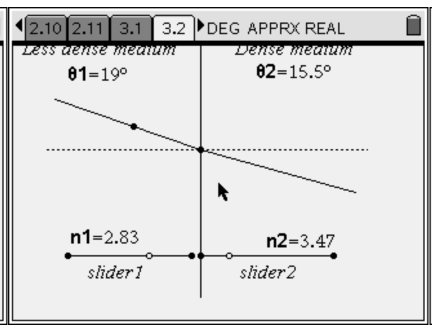
7. What does this equation indicate about the relationship between refractive index, angle of incidence, and angle of refraction?



	A	B	C xp	D yp	E xsl
◆					
1	-10.8	-7.75	-10.8	-7.75	
2			0.	0.	
3			10.8	2.26	
4					
5					

A1 =′x1

Use the sliders to explore how varying the values of **n1** and **n2** affect the amount of bending that takes place as light travels from one medium into another. Use manual data capture to record the values of **n1, n2, θ1,** and **θ2** in the spreadsheet on page 3.4. Do not change the angle of incidence during the data collection.

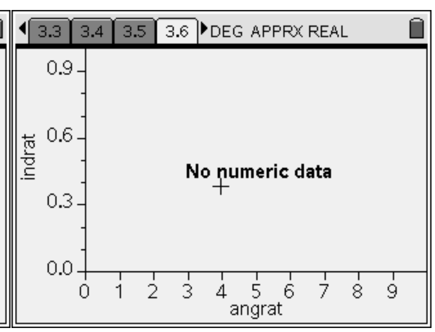


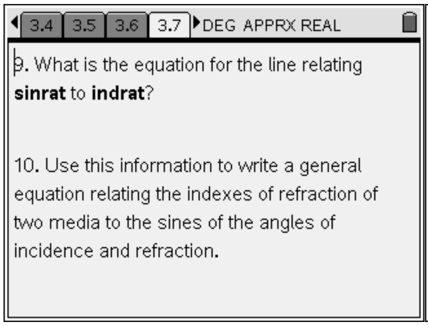
8. How does the relationship between **n1** and **n2** affect the amount of bending?

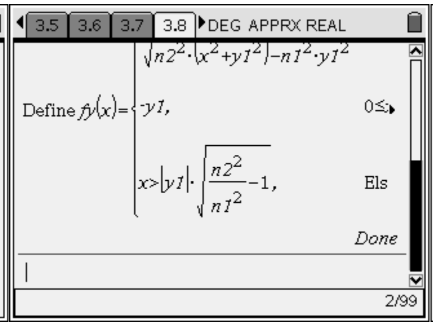
	A ang...	B an...	C ind1	D ind2	E sinrat
◆	=capture	=capture	=captur	=captur	=sin(angl
1					
2					
3					
4					
5					

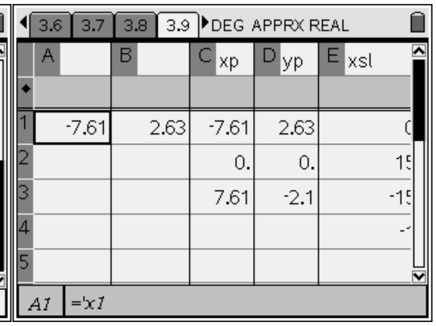
A1

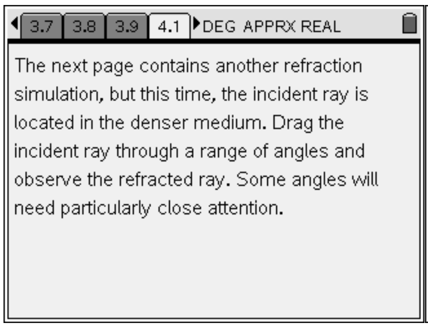
Page 3.6 shows a scatter plot of the ratio of **n1** to **n2** (**indrat**) vs. the ratio of the sine of the angle of refraction to the sine of the angle of incidence (**sinrat**).

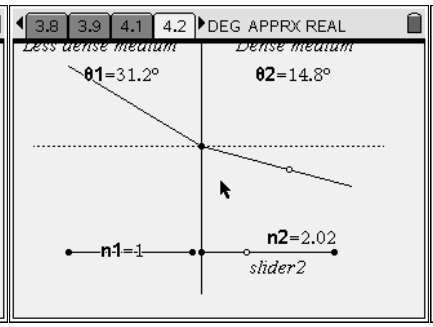


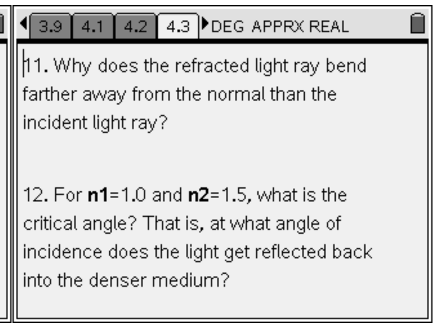

3.4 3.5 3.6 3.7 DEG APPRX REAL
9. What is the equation for the line relating **sinrat** to **indrat**?
10. Use this information to write a general equation relating the indexes of refraction of two media to the sines of the angles of incidence and refraction.

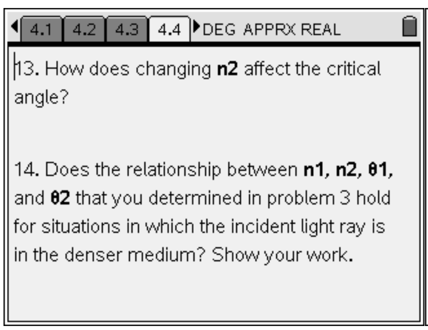

3.5 3.6 3.7 3.8 DEG APPRX REAL
Define fy(x)=
-y1,
0≤
Els
Done
2/99

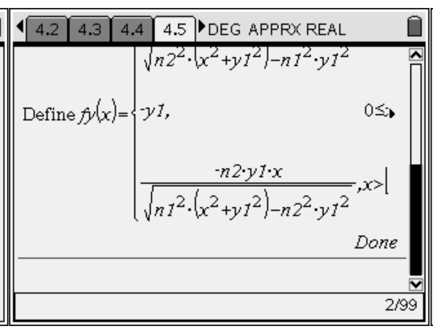

3.6 3.7 3.8 3.9 DEG APPRX REAL
A B C xp D yp E xsl
-7.61 2.63 -7.61 2.63
0. 0.
7.61 -2.1
A1 ='x1

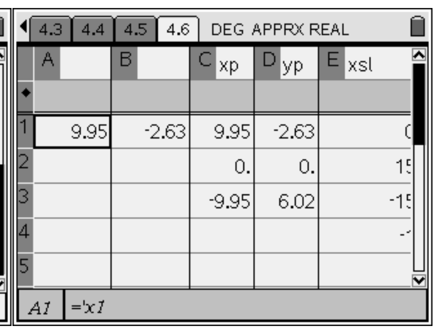

3.7 3.8 3.9 4.1 DEG APPRX REAL
The next page contains another refraction simulation, but this time, the incident ray is located in the denser medium. Drag the incident ray through a range of angles and observe the refracted ray. Some angles will need particularly close attention.


3.8 3.9 4.1 4.2 DEG APPRX REAL
θ1=31.2°
θ2=14.8°
n1=1
n2=2.02
slider2


3.9 4.1 4.2 4.3 DEG APPRX REAL
11. Why does the refracted light ray bend farther away from the normal than the incident light ray?
12. For **n1**=1.0 and **n2**=1.5, what is the critical angle? That is, at what angle of incidence does the light get reflected back into the denser medium?


4.1 4.2 4.3 4.4 DEG APPRX REAL
13. How does changing **n2** affect the critical angle?
14. Does the relationship between **n1, n2, θ1,** and **θ2** that you determined in problem 3 hold for situations in which the incident light ray is in the denser medium? Show your work.


4.2 4.3 4.4 4.5 DEG APPRX REAL
Define fy(x)=
-y1,
0≤
-n2·y1·x
Done
2/99


4.3 4.4 4.5 4.6 DEG APPRX REAL
A B C xp D yp E xsl
9.95 -2.63 9.95 -2.63
0. 0.
-9.95 6.02
A1 ='x1

