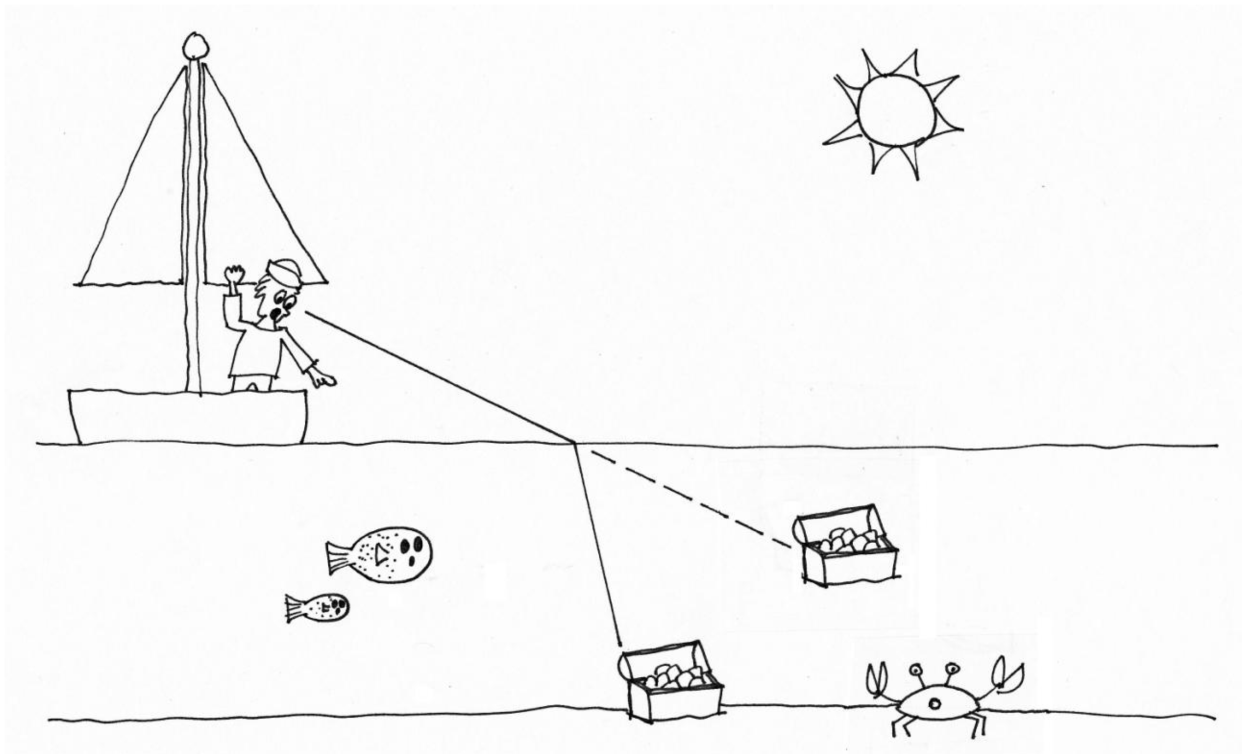
Index of Refraction:
Treasure at the Bottom of the Sea



Artwork by Shelly Lynn Johnson

When light moves from one material to another, the speed of the light changes. Refraction is the bending of a light ray when it moves from one medium (like air) to another (like glass or water). The amount of bending depends on the difference in speed of the light in the two different media. Snell's Law describes this relationship.

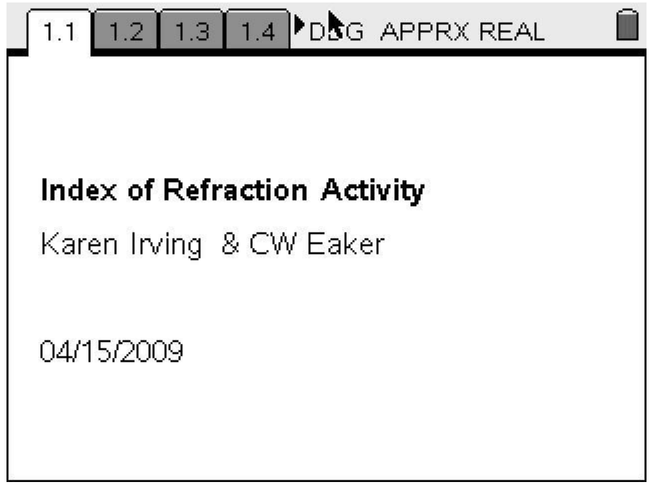
The refractive index of a material is an important optical property and is used to calculate the focusing power of lenses and the dispersive power of prisms. Refractive index is an important physical property of a substance that can be used for identification, purity determination or measurement of concentration.

This activity is designed for the Nspire handheld and intends to help students understand the refraction of light as it moves from one medium to another. Students will discover Snell's Law using an interactive diagram.

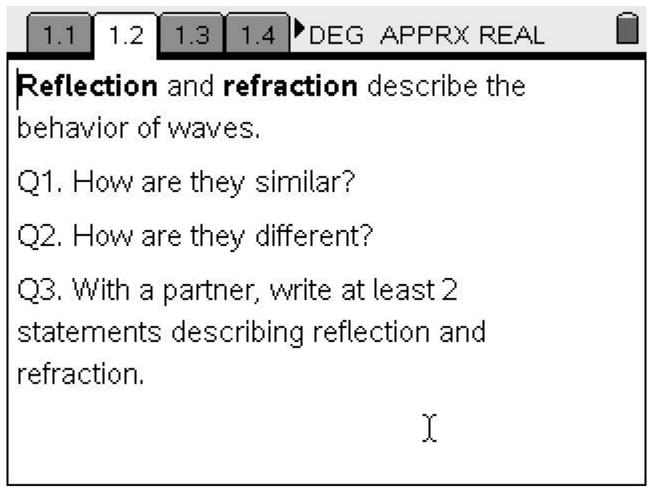
Introduction

1.1.Open the IRefracT.tns file.

- Read the first three pages of the document.



1.2 Reflection and refraction describe the behavior of waves. Students answer questions on handout. Use a think, pair, share strategy to invite students to respond.



Q1. How are they similar?

Both are properties of waves. Both describe a change in direction of waves.

Q2. How are they different?

Reflection describes the response of a wave when it cannot pass into a new medium. Refraction describes the response of a wave when it enters a new medium.

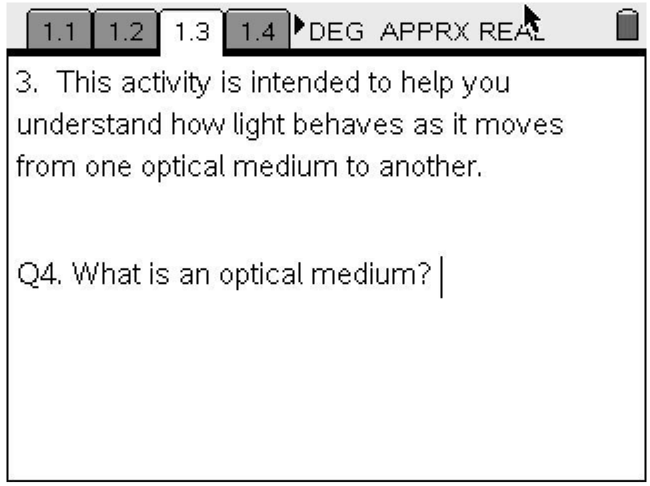
Q3. With a partner, write at least 2 statements describing reflection and refraction.

Sample sentences:

Reflection describes how waves bounce off of surfaces. The angle of incidence equals the angle of reflection.

Refraction describes how waves change direction when they enter a new medium. The angle of refraction is measured inside the new medium.

1.3 This activity is intended to help you understand how light behaves as it moves from one medium to another.

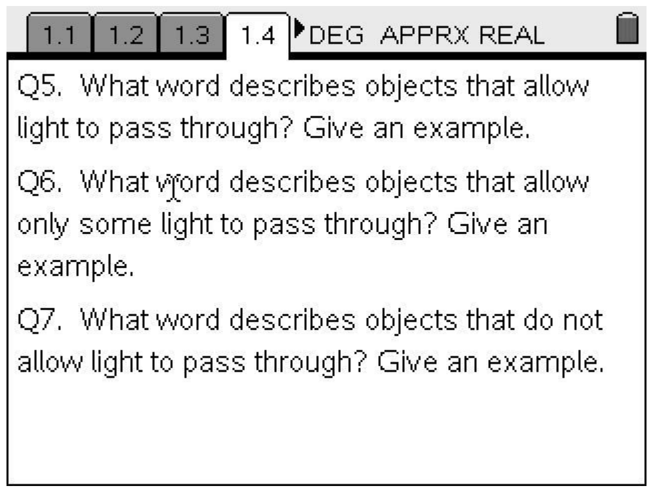


Q4. What is an optical medium?

An optical medium is a material through which waves can travel. Glass, air, and water are all examples of optical mediums.

Teacher note: ***Optical media*** *are not the same as an* ***optical medium****. Optical media like compact discs are circular discs used in video, computing and sound reproduction which carry data encoded on special surfaces.*

1.4



Q5. What word describes objects that allow light to pass through? Give an example of this type of medium.

A medium that allows the transmission of light is called transparent. Glass is an example.

Q6. What word describes objects that allow only some light to pass through? Given an example of this type of medium.

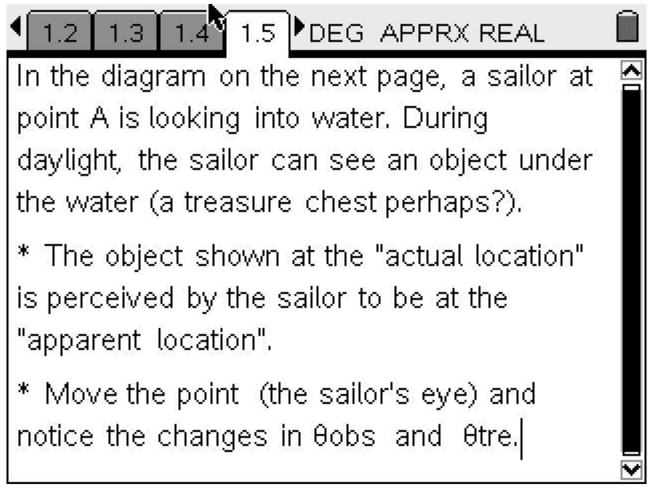
Translucent materials allow light to pass through diffusely. You cannot see through a translucent medium. Frosted glass is translucent – light passes through but you cannot make out images.

Q7. What word describes objects that do not allow light to pass through? Give an example of this type of medium.

An opaque medium transmits very little light. Most light is reflected, scattered or absorbed by the surface of an opaque substance. A blackboard and a rock are examples of opaque objects.

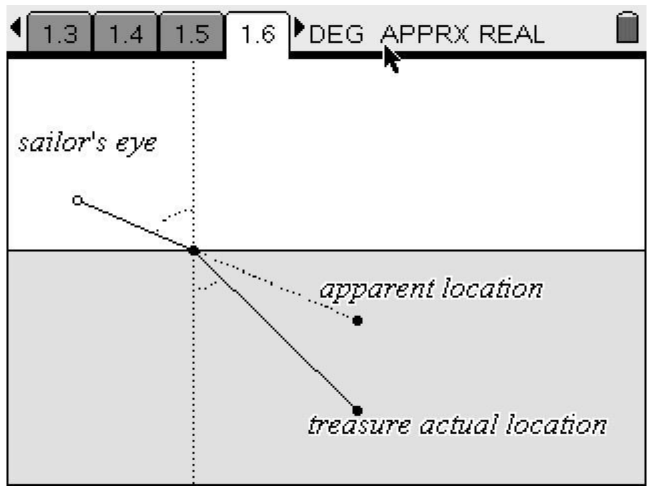
1.5 In the diagram, an observer (or sailor) at point A is looking into water.

- When a light source is present (like the sun), the observer can see an object under the water (perhaps a treasure chest).
- The object at the "actual location" is perceived by the sailor to be at the "apparent location."



1.6 Move point A and notice the changes in θ_{obs} and θ_{obj}.

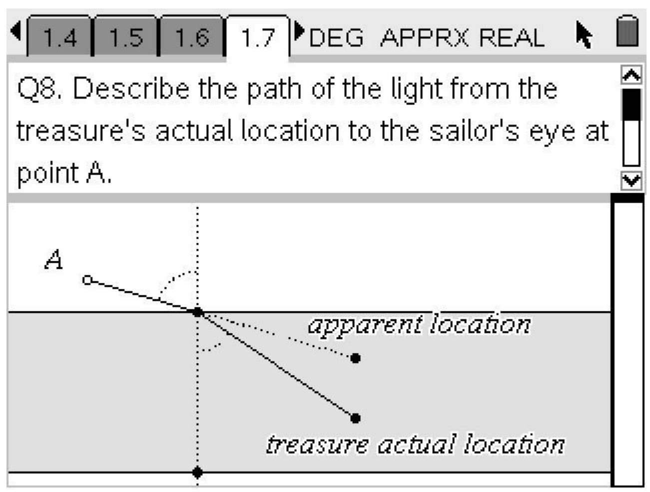
Use the NavPad to move close to the point at the end of the line, labeled sailor's eye. When an open hand appears, press the ctrl key followed by the to grab the point. Notice that the hand closes. You will be able to move point A. Notice that the values of θ_{obs} and θ_{obj} change as you change the position of point A.



1.7 Q8. Describe the path of the light from the actual location to the observer's eye at point A.

Remind students that the sun is the source of light for an object in the water. Some students may want to describe the path as if light is coming from the observer's eye to the object (a common and ancient naïve conception). This question provides teachers the opportunity to reinforce the point that the source of light in this problem is NOT the observer's eye but rather an external source such as the sun.

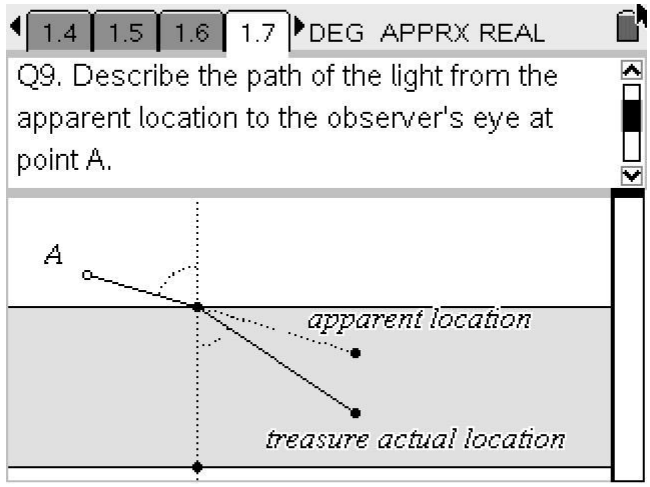
The light ray leaves the treasure and travels in a straight line to the surface of the water. At the surface, the ray bends towards the surface and then continues in a straight line to the sailor's eye.



Use ctrl tab to move between the two

sections (notes at the top versus interactive diagram at the bottom) of the screen.

1.7 b Q9. Describe the path of the light from the apparent location to the observer's eye at point A.

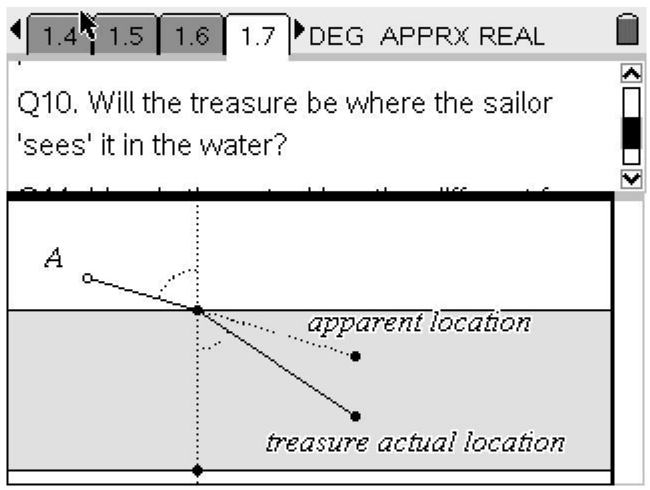


The light ray leaves the treasure and travels in a straight line to the sailor's eye. It does not bend when it moves across the boundary between the air and water.

Use ctrl tab to move between the two sections (notes at the top versus interactive diagram at the bottom) of the screen.

1.7c

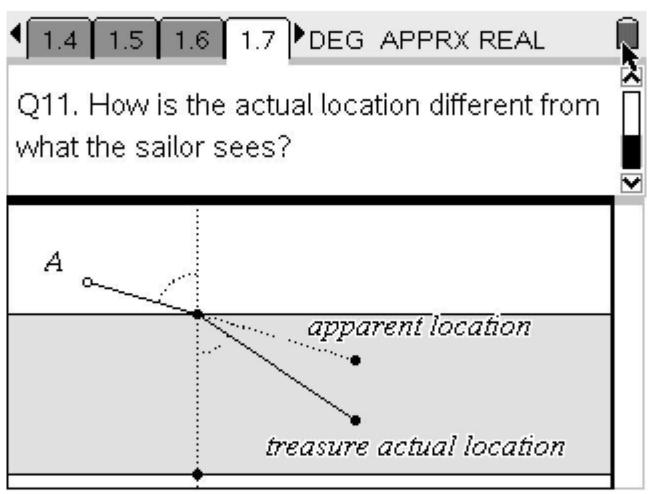
Q10 Will the treasure be where the sailor sees it in the water?



No, the object will not be located where the sailor thinks he or she sees it in the water. The actual location is different from the apparent location.

1.7d

Q11 How is the actual location different from what the sailor sees?

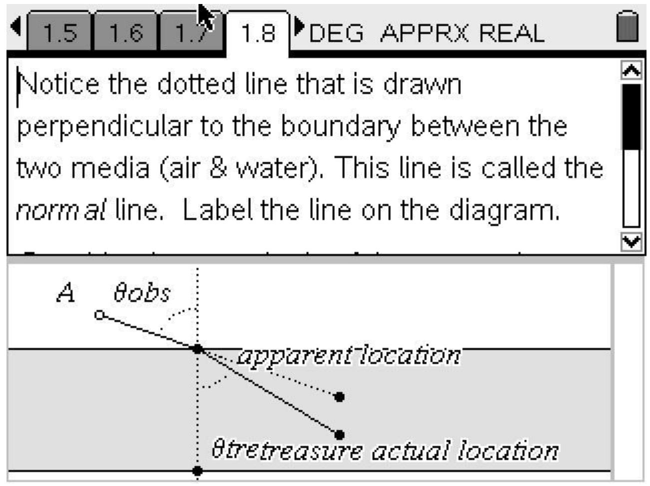


The actual location is deeper in the water than the apparent location. The actual location is below the apparent location.

1.8. Notice the dotted line that is drawn perpendicular to the boundary between the two media (air & water). This line is called the normal line. Label the line on the diagram.

To add a text box: Select menu Actions Text enter clear . You will see a box. Type in normal. Press enter again. Move the cursor away. You can select the text box and move it with the hand tool.

Consider the magnitude of the two angles.



Q12. Are they ever the same size?

Students will be challenged to answer this question. When the observed angle is large, the treasure angle seems very different in magnitude. As the observed angle approaches vertical, it's difficult to tell by just looking whether the angles are the same or not.

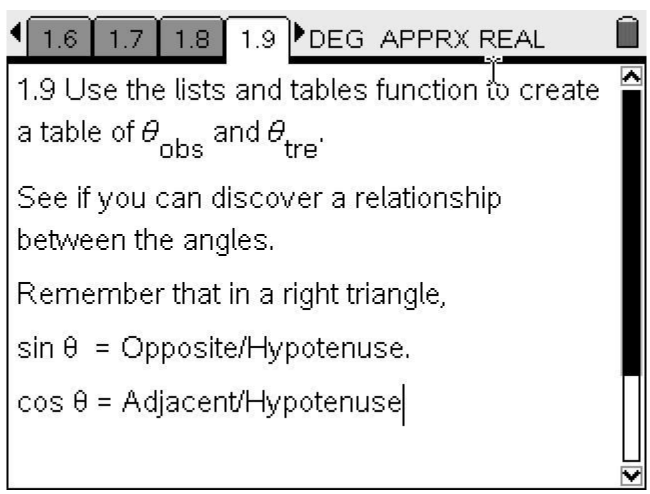
Q13. As θ_{obs} increases, what happens to θ_{tre}?

As θobs increases, θtre increases too. They seem to increase and decrease together.

1.9 Use the lists and tables function to create a table of θ_{obs} and θ_{tre}.

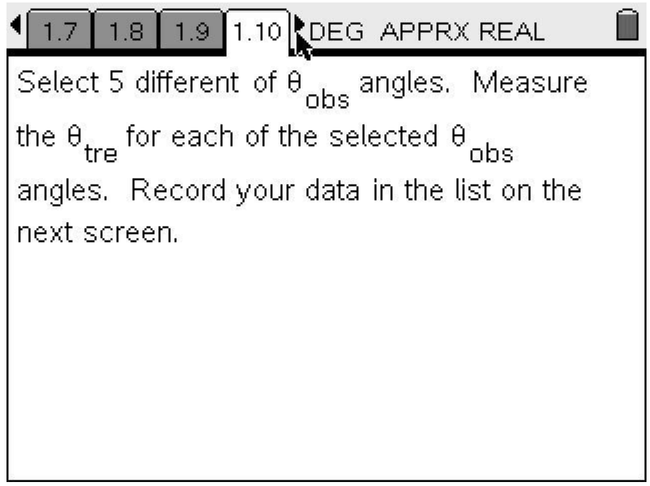
See if you can discover a relationship between the angles.

Remember that in a right triangle,
$\sin \theta$ = Opposite/Hypotenuse.
$\cos \theta$ = Adjacent/Hypotenuse



1.10 Select 5 different θ_{obs} angles. Measure the θ_{tre} for each of the selected θ_{obs} angles. Record your data in the list on the next screen.

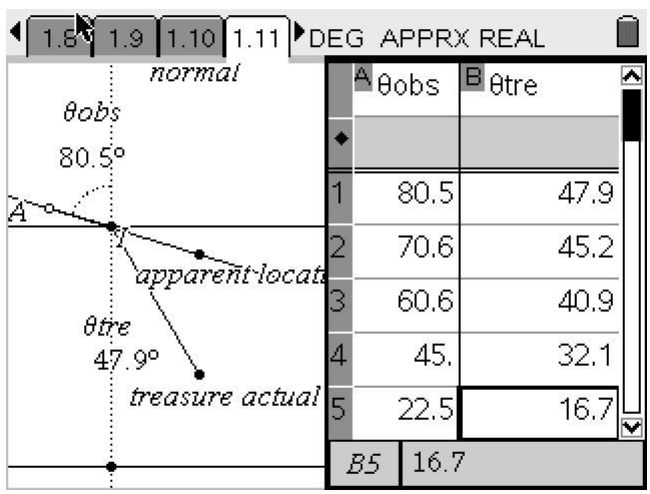
Note to teacher: Each student should collect 5 data points. You might try to specify θobs angles, but students may have difficulty getting their handheld to show the exact angles you specify. While there is no need for each student to have the same data, some teachers may find this preferable. Data could be collected from the teacher's demonstration unit and inputted manually by students.



Select 5 different of θ_{obs} angles. Measure the θ_{tre} for each of the selected θ_{obs} angles. Record your data in the list on the next screen.

Use the NavPad to move close to the point at the end of the line. When an open hand appears, press the ctrl key followed by the to grab the point. Notice that the hand closes. You will be able to move point A. Record the values of θ_{obs} and θ_{obj} as you change the position of point A to collect 5 different sets of angle values.

1.11 Record your data in the table. Each student will create their own unique data set. Be sure to include the digit after the decimal point as part of your data.



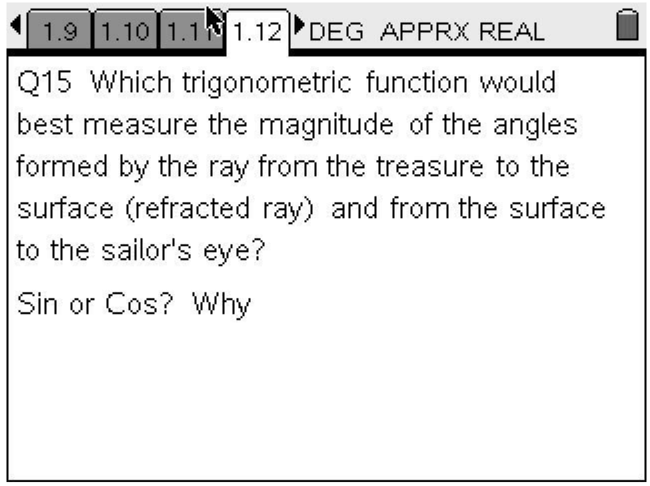
	A θobs	B θtre
◆		
1	80.5	47.9
2	70.6	45.2
3	60.6	40.9
4	45.	32.1
5	22.5	16.7

1.12

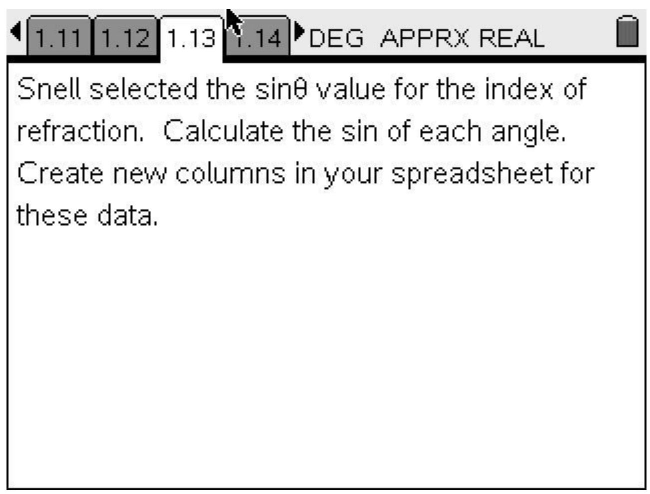
Q15 Which trigonometric function would best measure the magnitude of the angles formed by the ray from the treasure to the surface (refracted ray) and from the surface to the sailor's eye?

Sin or Cos? Why

Teacher Note: You may need to draw a right triangle on the board and identify the adjacent, opposite and hypotenuse for students. Help them see that the wideness of the observed angle is best reflected by the sin function - a ratio of opposite (distance measuring the open part of the angle) and the hypotenuse. You may prefer to just tell students to use the sin function at this point in the lesson. When preparing to teach, you could delete slide 1.12 and have students move directly to slide 1.13.

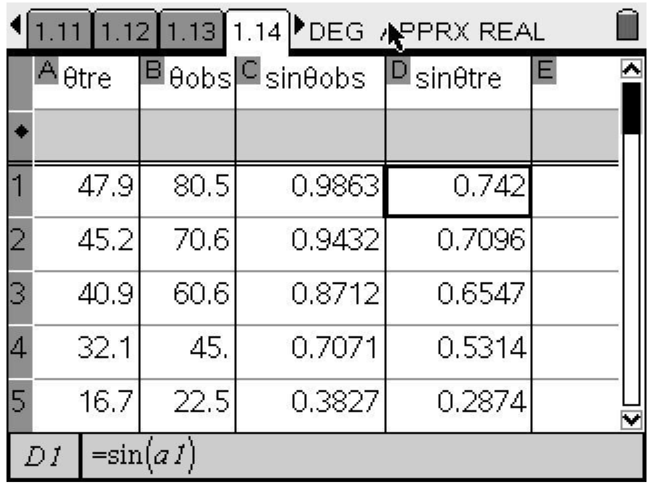


1.13 Snell selected the sin θ value for the index of refraction. Calculate the sin of each angle.



1.14 Create two new columns in your table, one for sin θ_{obs} and the other for sin θ_{tre}.

The θ symbol can be found in the catalog located by selecting (the symbol that looks like an open book with Greek symbols above). Select the symbol you want.



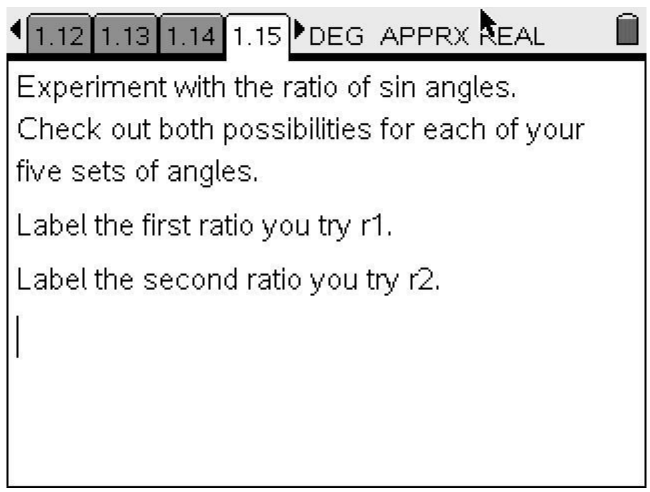
	A θtre	B θobs	C sinθobs	D sinθtre	E
1	47.9	80.5	0.9863	0.742	
2	45.2	70.6	0.9432	0.7096	
3	40.9	60.6	0.8712	0.6547	
4	32.1	45.	0.7071	0.5314	
5	16.7	22.5	0.3827	0.2874	

D1 =sin(a1)

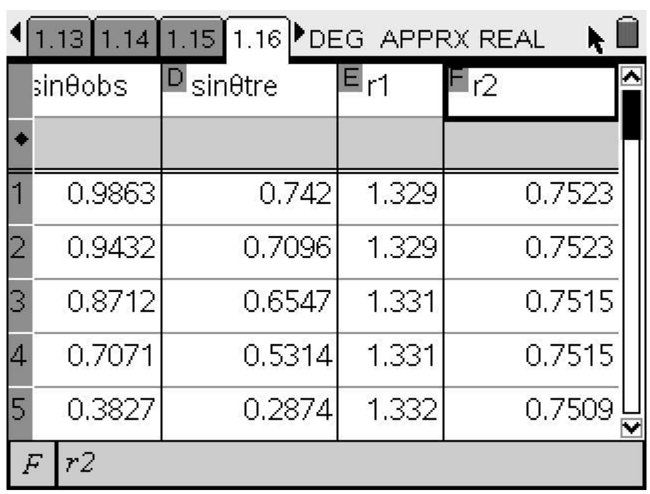
1.15 Experiment with the ratio of sin angles. Check out both possibilities for each of your five sets of angles.

R1 = sin θ_{obs} / sin θ_{tre} = c1/d1

R2 = sin θ_{tre}/ sin θ_{obs} = d1/c1



1.16. Try the opposite ratio too.



	sinθobs	D sinθtre	E r1	F r2
1	0.9863	0.742	1.329	0.7523
2	0.9432	0.7096	1.329	0.7523
3	0.8712	0.6547	1.331	0.7515
4	0.7071	0.5314	1.331	0.7515
5	0.3827	0.2874	1.332	0.7509

F r2

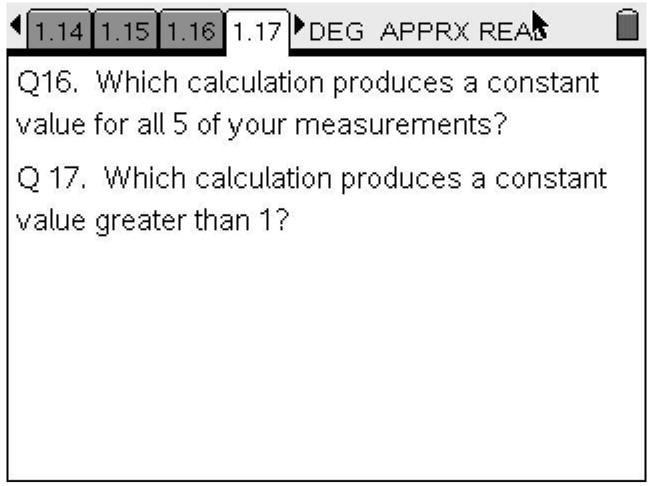
1.17 Study the values you have produced in the spreadsheet.

Q16. Which calculation produces a constant value for all 5 of your measurements?

Both calculations produce a constant value – this was Snell's contribution.

Q17. Which calculation produces a constant value greater than 1?

R1 produces a value greater than 1.



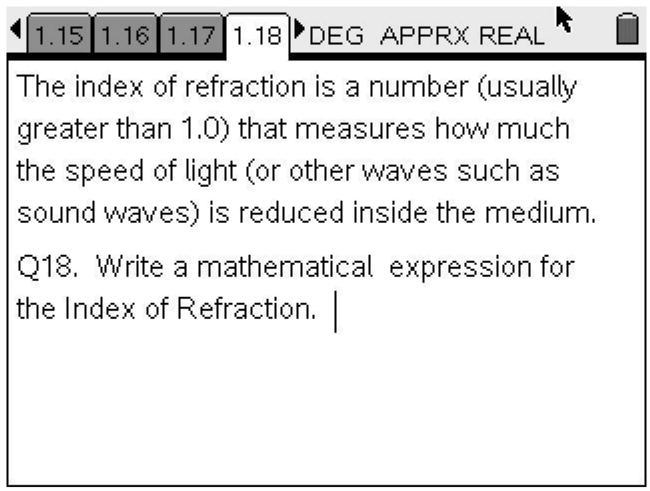
1.18 The index of refraction is a number (usually greater than 1.0) that measures how much the speed of light (or other waves such as sound waves) is reduced inside the medium.

Q18. Write a mathematical expression for the Index of Refraction. Note that often n_1 is 1.00 (index of refraction in a vacuum).

Snell's Law:
$$\frac{n_2}{n_1} = \frac{\sin\,\theta_1}{\sin\,\theta_2}$$

Or expressed without fractions:

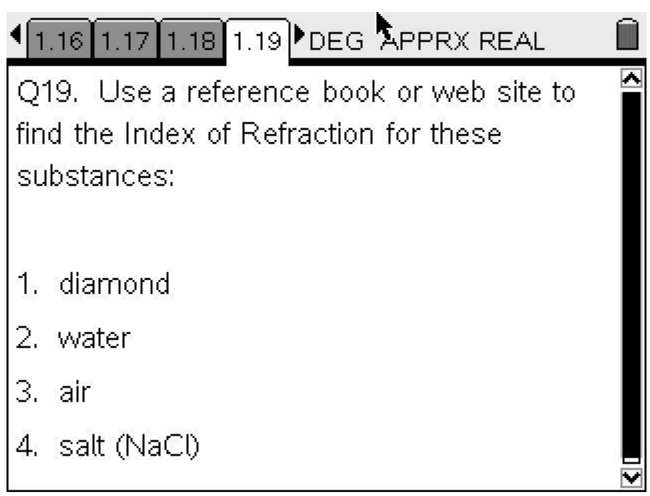
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



1.19

Q19. Use a reference book or web site to find the Index of Refraction for these substances:

1. diamond
2. water
3. air
4. salt (NaCl)



1.20

Q20.Which of these media will refract light the most?

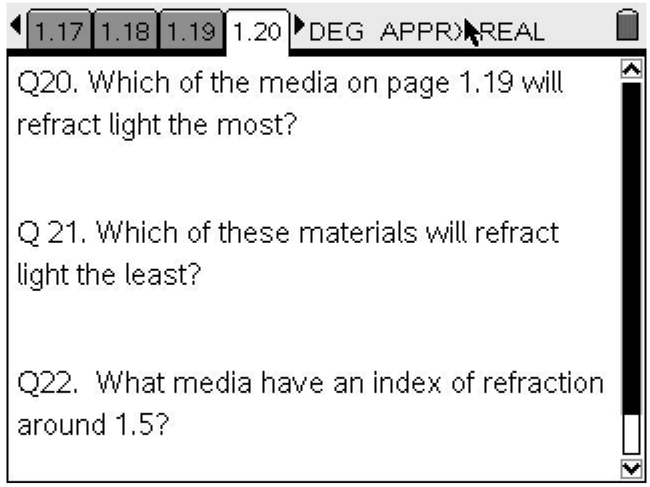
diamond

Q21.Which of these materials will refract light the least?

Air.

Q22.What media have an index of refraction around 1.5?

Different kinds of glass, NaCl, polystyrene all have values around 1.5



Indices of Refraction

Material	Index
Vacuum	1.00000
Air at STP	1.00029
Ice	1.31
Water at 20 C	1.33
Fluorite	1.433
Fused quartz	1.46
Typical crown glass	1.52
Crown glasses	1.52-1.62
Spectacle crown, C-1	1.523
Sodium chloride	1.54
Polystyrene	1.55-1.59
Flint glasses	1.57-1.75
Heavy flint glass	1.65
Extra dense flint, EDF-3	1.7200
Sapphire	1.77
Arsenic trisulfide glass	2.04
Diamond	2.417

Index of refraction source:
http://hyperphysics.phy-astr.gsu.edu/Hbase/tables/indrf.html#c1