Light Refraction

Read from **Lesson 1** of the **Refraction and Lenses** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l1a.html
http://www.physicsclassroom.com/Class/refrn/u14l1b.html
http://www.physicsclassroom.com/Class/refrn/u14l1c.html
http://www.physicsclassroom.com/Class/refrn/u14l1f.html

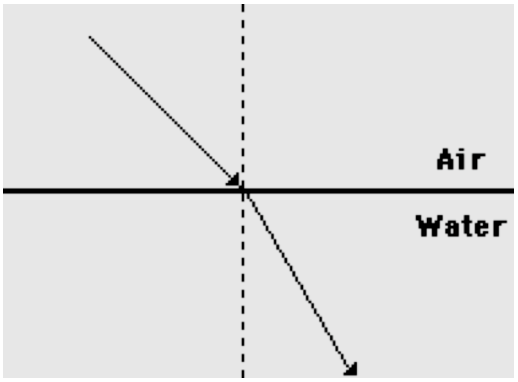
MOP Connection: Refraction and Lenses: sublevels 1 and 2

1. Write a one-word synonym for **refraction**. _____

2. Refraction occurs when light crosses the boundary between one material and another material. What is the primary cause for this refracting of light upon crossing a boundary?

The diagram below shows the path of a light ray as it travels through air, across the air-water boundary, and through the water. Use the diagram to answer questions #3-#6.

3. On the diagram, label ...
   - the air-water boundary with a **B**
   - the normal line with an **N**
   - the incident ray with an **I**
   - the refracted ray with an **R**
   - the angle of incidence with a θ_i
   - the angle of refraction with a θ_r



4. How many media are there in this diagram? _____ Name them.

5. What is meant by the term "medium" in this context?

6. Place a noticeable dot at the location where refraction of light takes place.

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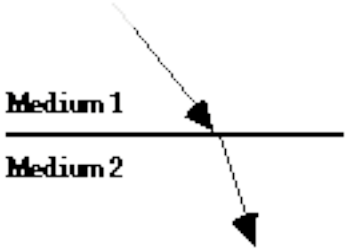
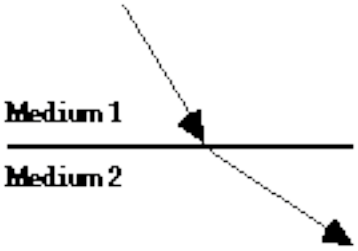
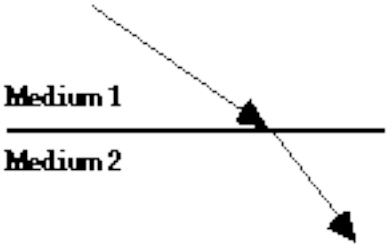
7. For the three situations below, draw a normal line and measure and record the angles of incidence and the angles of refraction.



θ_i = _____
θ_r = _____



θ_i = _____
θ_r = _____



θ_i = _____
θ_r = _____

8. As light passes from one medium into another, it refracts. There is only one condition in which light will cross a boundary but not refract. State this condition.

Direction of Bending

Read from **Lesson 1** of the **Refraction and Lenses chapter** at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l1d.html
http://www.physicsclassroom.com/Class/refrn/u14l1e.html
http://www.physicsclassroom.com/Class/refrn/u14l1f.html

MOP Connection: Refraction and Lenses: sublevels 2 and 3

1. The **optical density** is the property of a medium that provides a relative measure of the speed at which light travels in that medium. Light travels _____ (fastest, slowest) in media with a greater optical density.

2. Every transparent material is characterized by a unique **index of refraction** value (**n**). The index of refraction value is a numerical value that provides a relative measure of the speed of light in that particular material. Light travels _____ (fastest, slowest) in media with a higher index of refraction value.

3. The speed of light (**v**) in a material is determined using the speed of light in a vacuum (**c**) and the index of refraction (**n**) of the material. Calculate the speed of light in the following materials.

$$v = \frac{c}{n} = \frac{3.00 \times 10^8 \text{ m/s}}{n}$$

   a. water (n = 1.33): _____ b. glass (n = 1.50): _____

   c. ice (n = 1.31): _____ d. diamond (n = 2.42): _____

4. When light passes into a medium in which it travels faster, the light will refract _____ the normal. When light passes into a medium in which it travels slower, light will refract _____ the normal.
   a. towards, away from b. away from, towards

5. When light passes into a medium that is more optically dense, the light will refract _____ the normal. When light passes into a medium that is less optically dense, the light will refract _____ the normal.
   a. towards, away from b. away from, towards

6. Consider the refraction of light in the five diagrams below. In which case is the light bending towards the normal line? Circle all that apply.

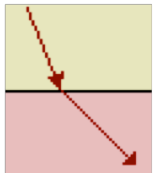
Diagram A 

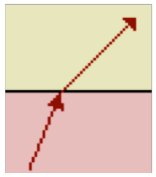
Diagram B 

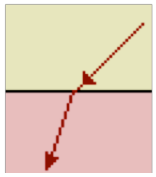
Diagram C 

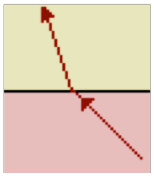
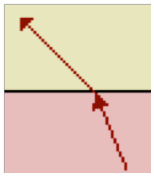
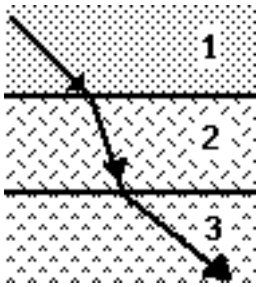
Diagram D 

Diagram E 

Consider the diagram at the right in answering the next four questions.



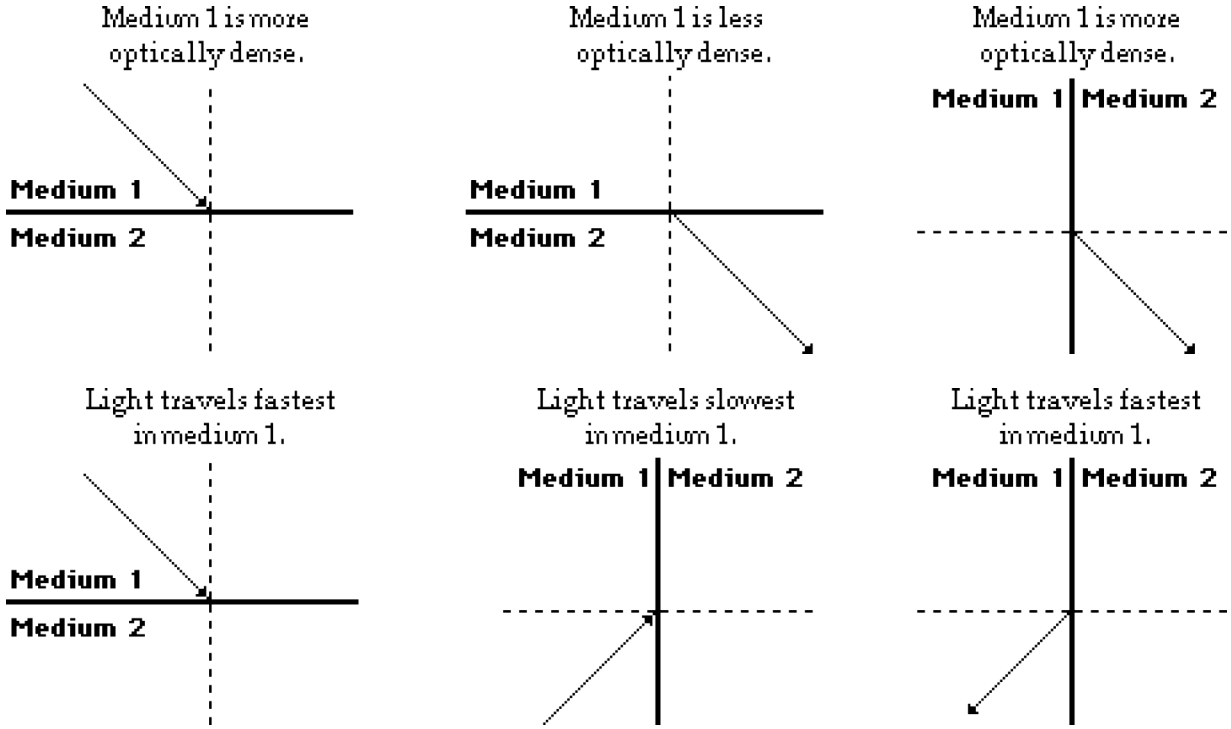
7. There are ___ (1, 2, 3, ...) media shown in the diagram.

8. There are ___ (1, 2, 3, ...) boundaries shown in the diagram.

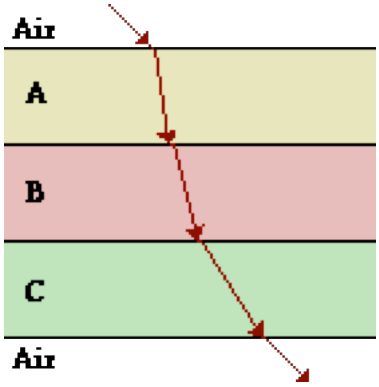
9. Light must travel _____ in medium 1 compared to medium 2.
   a. slower b. faster c. insufficient info

10. Light must travel _____ in medium 2 compared to medium 3.
    a. slower b. faster c. insufficient info

11. In each diagram, draw the "missing" ray (either incident or refracted) in order to appropriately show that the direction of bending is towards or away from the normal.



12. A ray of light is shown passing through three consecutive *layered* materials. Observe the direction of bending at each boundary and rank the three materials (A, B and C) in order of increasing index of refraction.



_____ < _____ < _____

smallest largest

13. Arthur Podd's method of fishing involves spearing the fish while standing on the shore. The apparent location of a fish is shown in the diagram below. Because of the refraction of light, the observed location of the fish is different than its actual location. If Arthur is to successfully spear the fish, must he aim at, below, or above where the fish appears to be? _____ Explain.

Snell's Law

Read from **Lesson 2** of the **Refraction and Lenses chapter** at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l2b.html
http://www.physicsclassroom.com/Class/refrn/u14l2c.html
http://www.physicsclassroom.com/Class/refrn/u14l2d.html

MOP Connection: Refraction and Lenses: sublevel 4

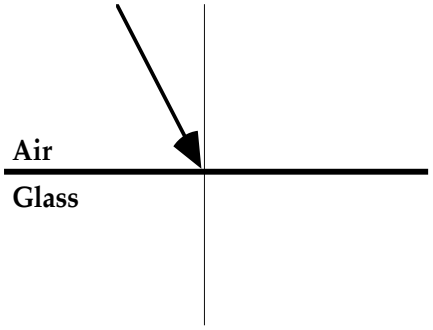
Math Review:
To find an angle measure for which the sine value is 0.8660, enter

2nd **Sin** **(0.8660)**

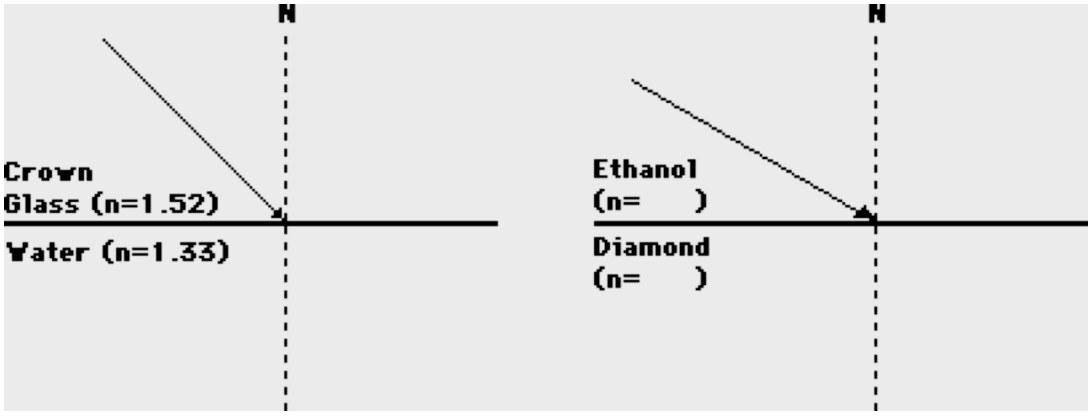
into your TI graphing calculator and press the Enter key. The angle is 59.99... degrees.

1. Use Snell's law to solve the following physics word problems. **PSYW**
   a. An incident ray in air (n=1.0) is approaching the boundary with an unknown material at an angle of incidence of 61.6°. The angle of refraction is 41.4°. Determine the index of refraction of the unknown material.

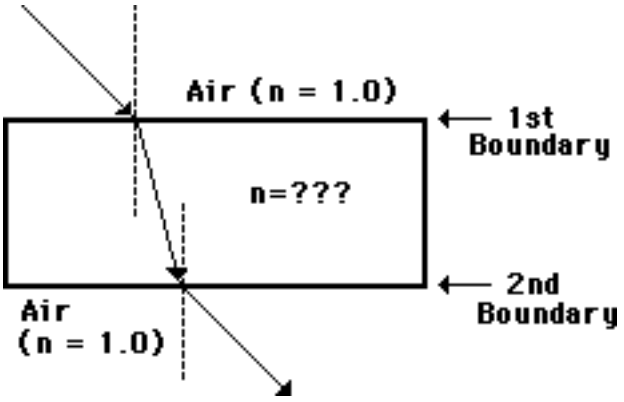
   b. An incident ray in air (n=1.0) is approaching the boundary with glass (n = 1.52) at an angle of incidence of 32.5°. Calculate the angle of refraction. Draw the refracted ray on the diagram at the right.



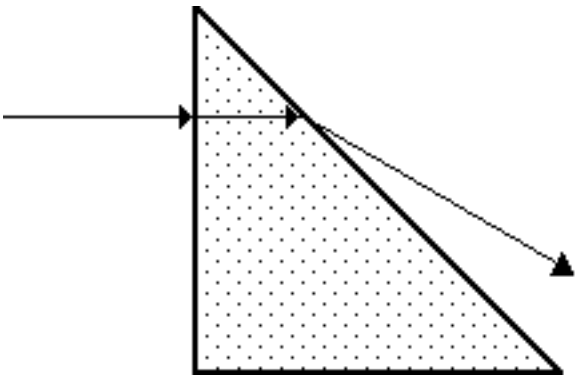
2. For the following two situations, measure and record θ_i, calculate θ_r, and draw in the refracted ray with the calculated angle of refraction. **PSYW**



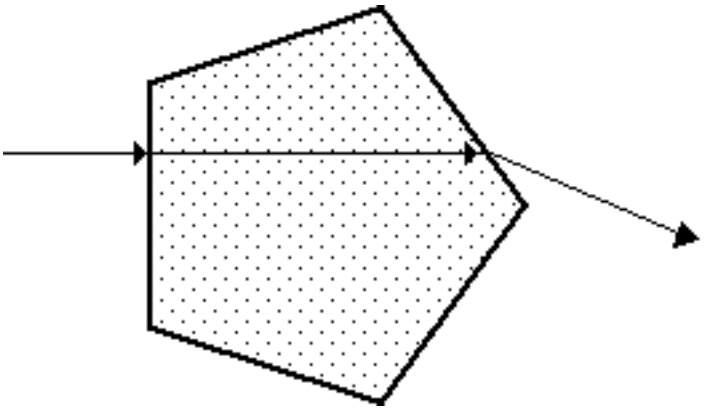
3. The diagram at the right shows a light ray entering a rectangular block of unknown material and subsequently exiting the block on the opposite side. The path of the light ray through the block is shown. Determine the index of refraction of the unknown material. Perform two calculations - one for each boundary - using Snell's law and the measured angles. **PSYW**



4. Cal Culator is performing experiments to determine the index of refraction of two unknown materials. Cal determines that the light follows the paths as shown on the diagrams below. Use this path, a protractor, a calculator and Snell's Law to determine the index of refraction of the unknown material. Show all your work in the space beside the diagram.



Show your work below:



Show your work below:

Total Internal Reflection

Read from **Lesson 3** of the **Refraction and Lenses chapter** at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l3a.html
http://www.physicsclassroom.com/Class/refrn/u14l3b.html
http://www.physicsclassroom.com/Class/refrn/u14l3c.html

MOP Connection: Refraction and Lenses: sublevels 5 and 6

Background:

Whenever a light ray reaches the boundary with a transparent medium, a portion of the light energy is transmitted across the boundary and appears as a refracted ray; and a portion of the energy remains within the original medium and appears as a reflected ray. The path of the refracted ray follows **Snell's law**. The path of the reflected ray follows the **law of reflection**. The amount of light energy that is reflected and transmitted is dependent upon the angle of incidence. At certain angles, all of the light is reflected (none is transmitted) and remains inside the original medium. This is known as total internal reflection (TIR).

1. Light will undergo total internal reflection only when it is _____. Choose two.
   a. in the less dense medium traveling towards the more dense medium
   b. in the more dense medium traveling towards the less dense medium
   c. in the medium where it travels slowest, moving towards the medium where it travels fastest
   d. in the medium where it travels fastest, moving towards the medium where it travels slowest

2. Total internal reflection is most likely to occur when _____.
   a. the angles of incidence are smaller (e.g., close to 0 degrees)
   b. the angles of incidence are greatest (e.g., close to 90 degrees)

Complete the following blanks by answering questions #3-#4:

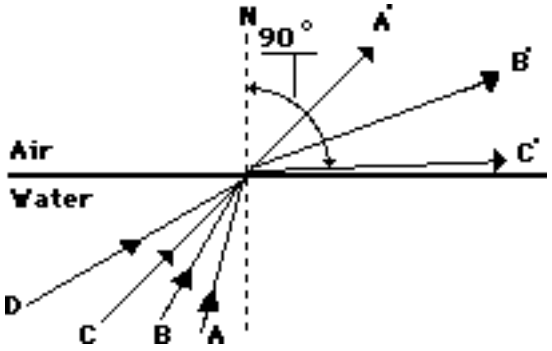
The critical angle is the angle of _____(#3)_____ that causes light to _____(#4)_____.

3. Referring to the statement above:
   a. incidence b. refraction c. reflection

4. Referring to the statement above:
   a. cross the boundary without refracting
   b. undergo refraction at the same angle as the angle of incidence
   c. refract at an angle of refraction of 90 degrees
   d. reflect at the same angle as the angle of incidence

The next three questions focus on the brightness of the reflected and refracted rays and the dependency of the brightness upon the angle of incidence.

5. Consider the diagram at the right for rays **A**, **B**, **C**, and **D** incident upon a water-air boundary. The corresponding refracted rays are shown. Draw the corresponding reflected rays and label them as **A"**, **B"**, **C",** and **D"**.

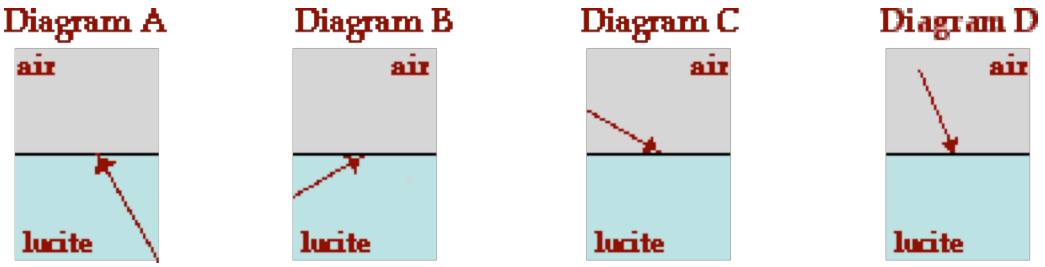


6. As the angle of incidence is gradually increased, more and more of the energy from the incident ray goes into the reflected ray, while less and less of the energy goes into the **refracted** ray. Based on this fact, which one of the refracted rays in the diagram would be brightest and which one would be dimmest?

Brightest: _____ **Dimmest**: _____

7. For incident ray **C**, the angle of refraction is 90°. The refracted ray C has the smallest amount of energy of any refracted ray. Thus, it would be an extremely "dim" light ray. What is the angle of incidence for ray **C** called?

8. The critical angle for an air (n=1.0) - Lucite (n=1.4) boundary is approximately 46 degrees. Which of the following diagrams depict incident rays that would undergo total internal reflection (TIR) at the angle shown? Circle all that apply.



9. Calculate the critical angle for the ....
   a. ... air (n = 1.00) - water (n = 1.33) boundary:

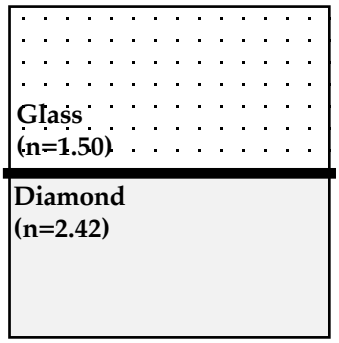
   b. ... air (n = 1.00) - diamond (n = 2.42) boundary:

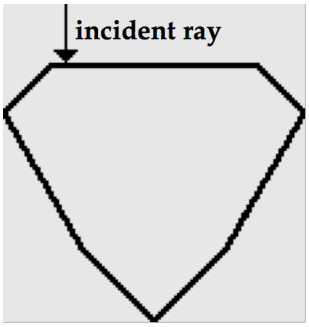
   c. ... water (n = 1.33) - glass (n = 1.50) boundary:

10. a. Calculate the critical angle for the boundary between glass (n = 1.50) and diamond (n = 2.42). **PSYW**

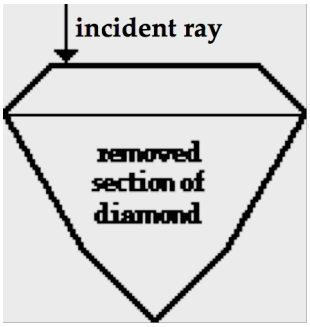
    b. On the diagram at the right, draw an incident ray that approaches the boundary with an angle equal to the critical angle. Label the incident ray as **A**. Draw the corresponding refracted ray and label the ray as **B**.

    c. Draw an incident ray that would approach the boundary at an angle greater than the critical angle. Label this incident ray as **C**.





11. Diamonds are usually cut with a shape similar to that shown at the right. Kent Affordit is preparing to propose to Amanda Befrendswyth. In an effort to save money, Kent asked the jeweler to remove the bottom portion of the gem. Kent reasoned that since it was not visible, its removal would have little consequence to its ultimate appearance. Explain why Kent never did get engaged to Amanda. Finally, draw the path of the given incident ray in each diamond.



Lenses

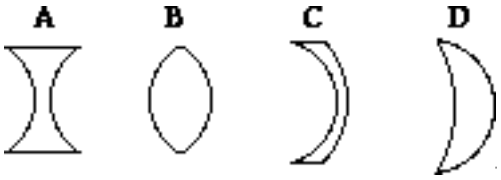
Read from **Lesson 5** of the **Refraction and Lenses chapter** at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l5a.html
http://www.physicsclassroom.com/Class/refrn/u14l5b.html
http://www.physicsclassroom.com/Class/refrn/u14l5c.html

MOP Connection: Refraction and Lenses: sublevel 7

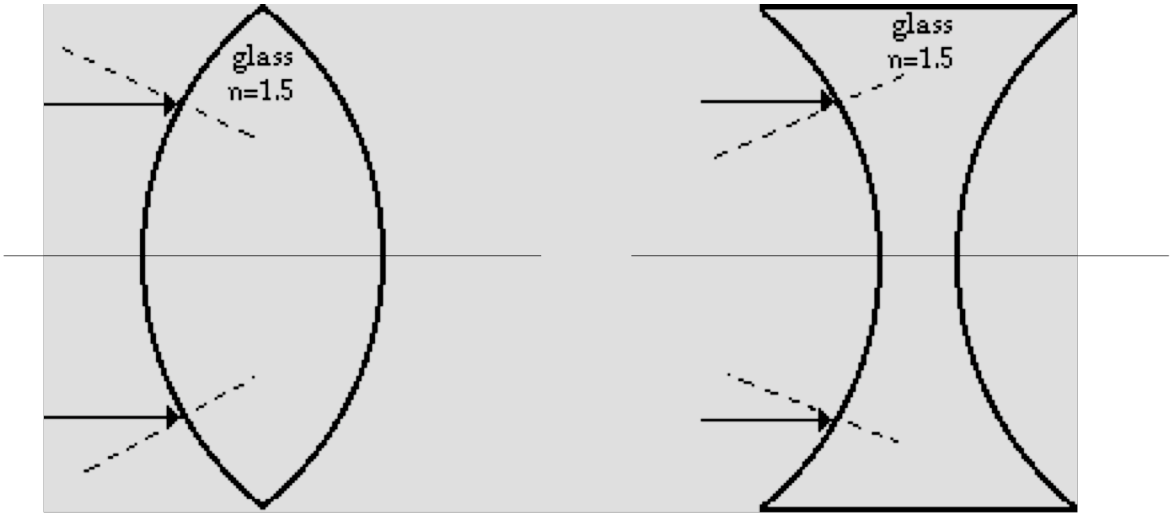
1. Converging lenses are _____ at the center and _____ at the edges.
   a. thickest, thinnest b. thinnest, thickest
2. Diverging lenses are _____ at the center and _____ at the edges.
   a. thickest, thinnest b. thinnest, thickest

Consider the diagram at the right in answering the next two questions.



3. List the letters of all the converging lenses.
4. List the letters of all the diverging lenses.

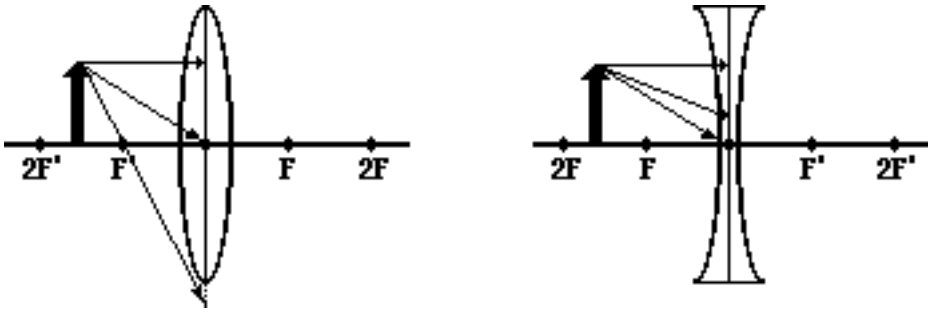
5. Use refraction principles to sketch an approximate path of light as it enters and exits the lens. Think FST and SFA. Trace the path of the rays into, through and out of the lens. Repeat the procedure for the light rays exiting the lens and trace the emerging light rays. Place arrowheads on all light rays.



6. Explain why lenses (like the one on the left above) are called "converging" lenses.

7. Converging lenses will have _____ (positive, negative) focal lengths. Diverging lenses will have _____ (positive, negative) focal lengths.

8. The diagram below shows an *arrow object* positioned in front of a converging and a diverging lens. Three incident rays are shown. Construct the corresponding refracted rays. Show arrowheads.



9. State the three *rules of refraction* for converging lenses:

#1: _____

_____

#2: _____

_____

#3: _____

_____

10. State the three *rules of refraction* for diverging lenses:

#1: _____

_____

#2: _____

_____

#3: _____

_____

11. The diagrams below depict the refraction of light through various lenses. List the diagrams that show the proper refraction of light. _____ For those which show the improper refraction of light, either correct the diagrams by showing the proper refracted rays or explain what is wrong with the refracted rays.

Diagram A

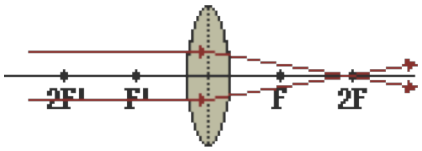


Diagram B

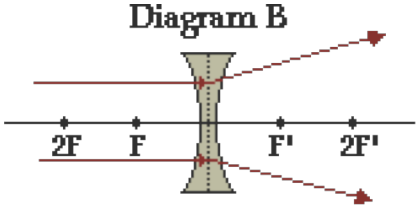


Diagram C

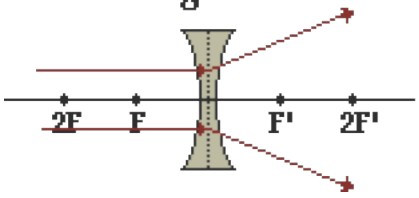
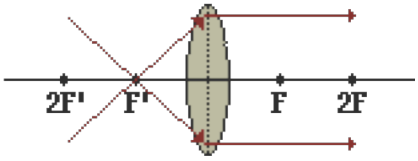


Diagram D



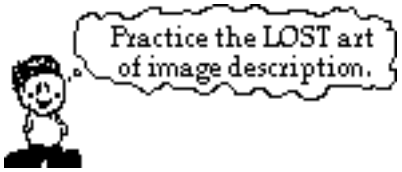
Ray Diagrams for Converging Lenses

Read from **Lesson 5** of the **Refraction and Lenses chapter** at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l5da.html
http://www.physicsclassroom.com/Class/refrn/u14l5db.html

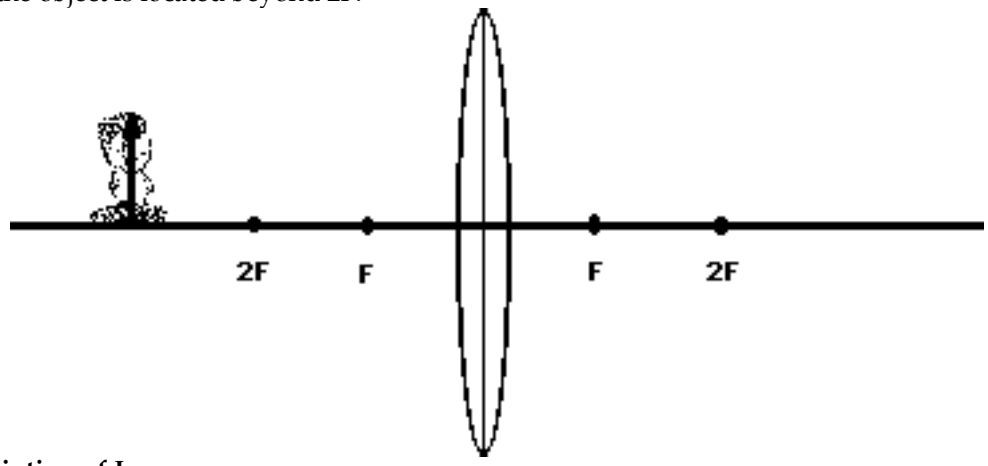
MOP Connection: Refraction and Lenses: sublevels 8 and 9

For the following lenses and corresponding object positions, construct ray diagrams. Then describe the **L**ocation of the image, **O**rientation (upright or inverted) of the image, the relative **S**ize of the image (larger or smaller than object), and the **T**ype of image (real or virtual). For **Case 4**, merely construct the ray diagram.



NOTE: 1) All light rays have arrowheads that indicate the direction of travel of the ray.
2) Always draw in the image once located (an arrow is a good representation).
3) Exactness counts. Use a straight-edge and be accurate.

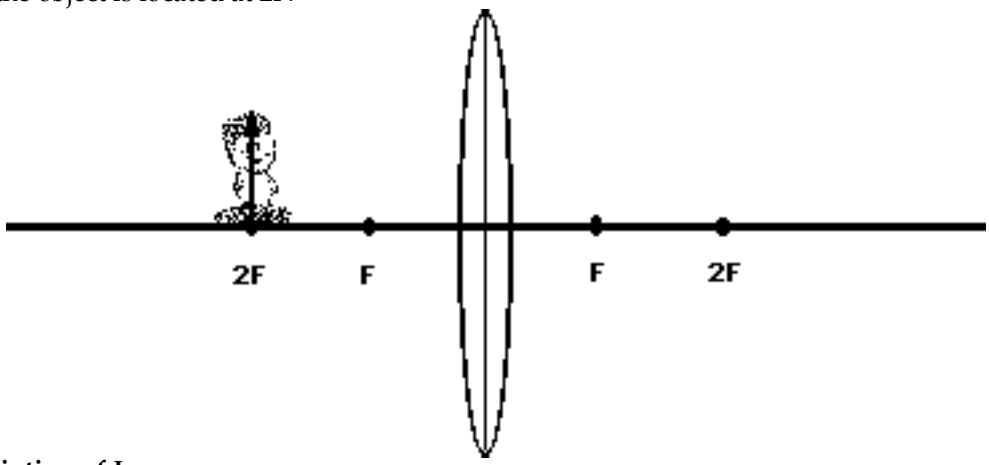
Case 1: If the object is located beyond 2F:



Description of Image:
Location: _____

O: Upright or Inverted **S:** Magnified or Reduced **T:** Real or Virtual

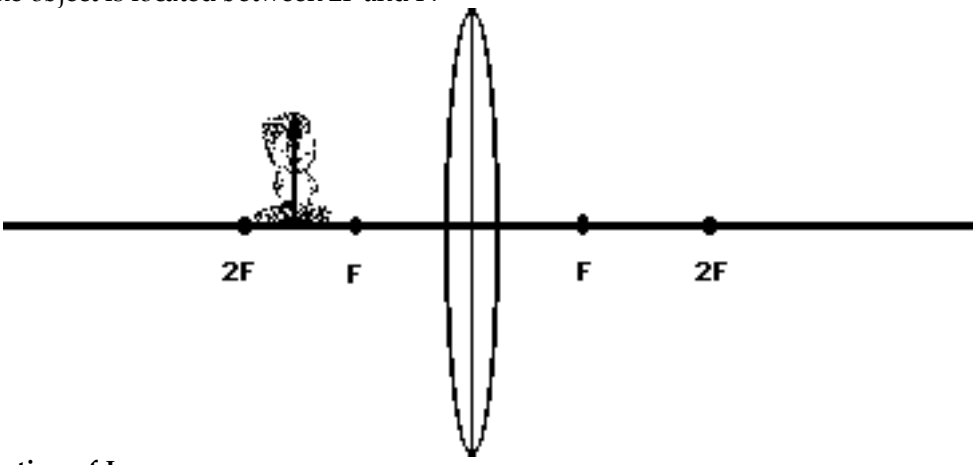
Case 2: If the object is located at 2F:



Description of Image:
Location: _____

O: Upright or Inverted **S:** Magnified or Reduced **T:** Real or Virtual

Case 3: If the object is located between 2F and F:

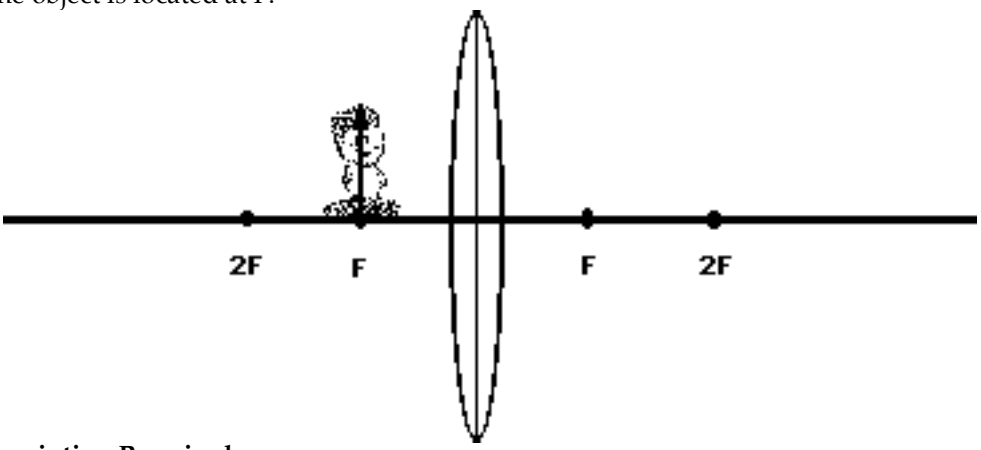


Description of Image:

Location: _____

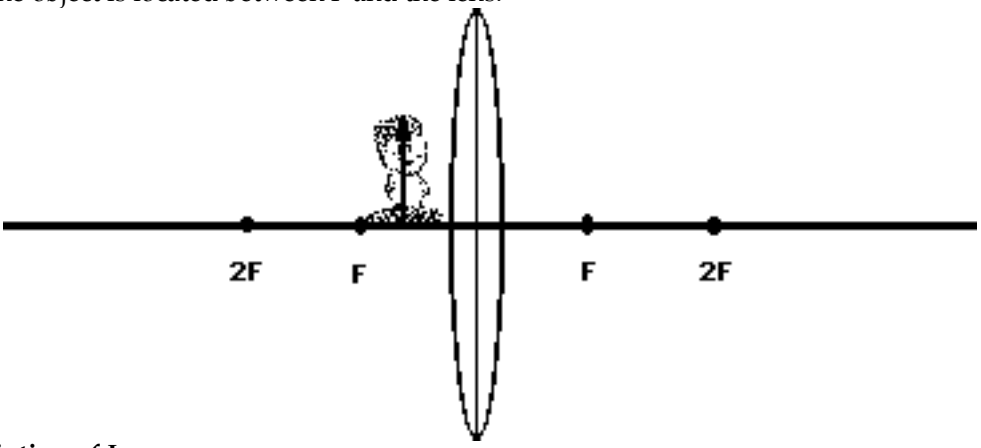
O: Upright or Inverted **S:** Magnified or Reduced **T:** Real or Virtual

Case 4: If the object is located at F:



No Description Required

Case 5: If the object is located between F and the lens:



Description of Image:

Location: _____

O: Upright or Inverted **S:** Magnified or Reduced **T:** Real or Virtual

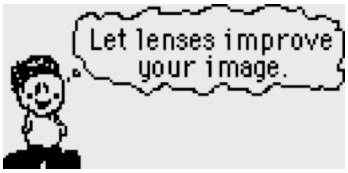
Ray Diagrams for Diverging Lenses

Read from **Lesson 5** of the **Refraction and Lenses** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l5ea.html
http://www.physicsclassroom.com/Class/refrn/u14l5eb.html

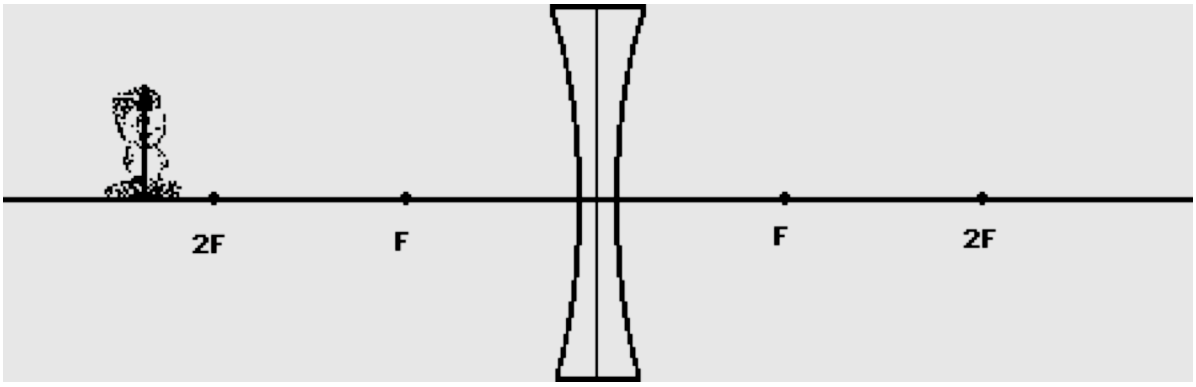
MOP Connection: Refraction and Lenses: sublevels 10 and 11

For the following lenses and corresponding object positions, construct ray diagrams. Then describe the **L**ocation of the image, **O**rientation (upright or inverted) of the image, the relative **S**ize of the image (larger or smaller than object), and the **T**ype of image (real or virtual).



NOTE: 1) All light rays have arrowheads that indicate the direction of travel of the ray.
2) Always draw in the image once located (an arrow is a good representation).
3) Exactness counts. Use a straight-edge and be accurate.

Case 1: If the object is located far away from the lens:

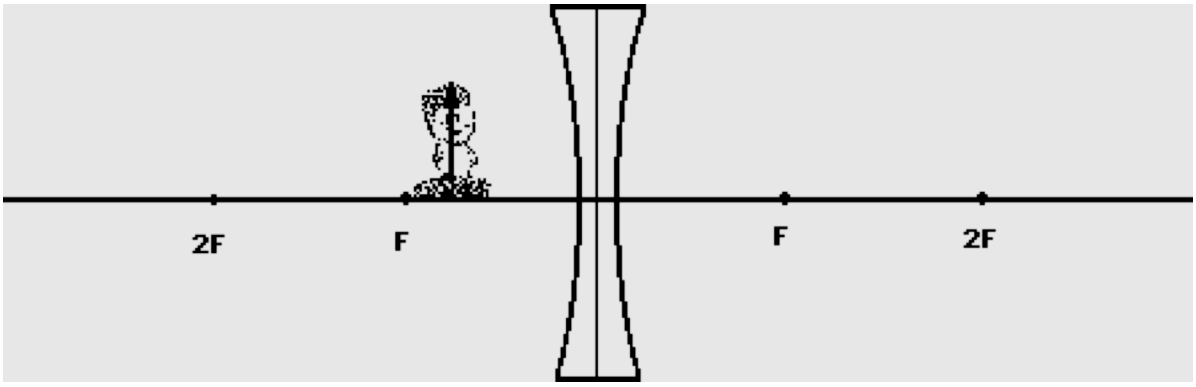


Description of Image:

Location: _____

O: Upright or Inverted **S:** Magnified or Reduced **T:** Real or Virtual

Case 2: If the object is located nearby the lens:



Description of Image:

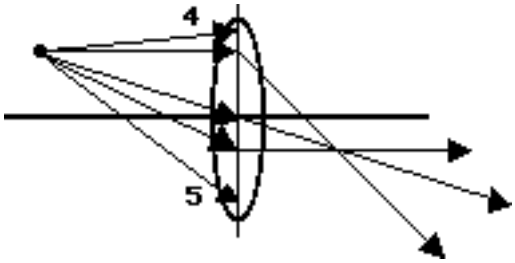
Location: _____

O: Upright or Inverted **S:** Magnified or Reduced **T:** Real or Virtual

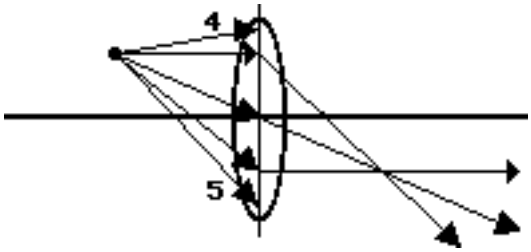
Lenses and Mirrors - Applying Concepts

1. Light emanates in a variety of directions from the following point objects; some of this light is incident towards the mirror or lens. The behavior of a few such incident rays is shown below. Show how the third, fourth and/or fifth incident rays refract or reflect.

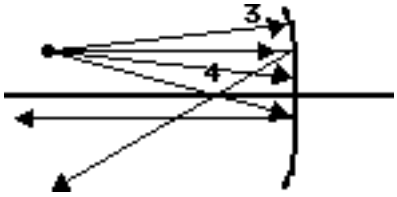
Converging Lens



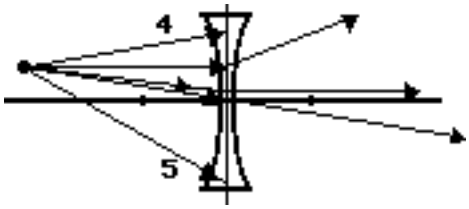
Converging Lens



Concave Mirror



Diverging Lens



2. Several statements about images are given below. Identify which optical device applies to the given statement. Place the appropriate marks in the blanks. Mark all that apply.

A = plane mirrors **B = concave mirrors** **C = convex mirrors**
D = converging lenses **E = diverging lenses**

a. Are capable of producing real images. _____

b. Only produce virtual images. _____

c. Are capable of producing enlarged images. _____

d. Can only produce images that are smaller than the object. _____

e. Capable of producing images the same size as the object. _____

3. Identify the following statements as being either true (**T**) or false (**F**).

a. If reflected or refracted rays diverge, there is no image. _____

b. If an object is located in front of a focal point, there is no image. _____

c. Virtual images cannot be seen. _____

d. All images are formed by the actual convergence of reflected or refracted light. _____

e. Just three rays of light from an object can intersect at the image location. _____

Lens Practice

Read from **Lesson 5** of the **Refraction and Lenses chapter** at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/refrn/u14l5f.html

Use the lens equation and magnification equation to solve the following problems.

1. Determine the image distance and image height for a 4.0-cm tall object placed 54.0-cm from a converging lens having a focal length of 18.0 cm.

2. Determine the image distance and image height for a 4.0-cm tall object placed 36.0-cm from a converging lens having a focal length of 18.0 cm.

3. Determine the image distance and image height for a 4.0-cm tall object placed 24.0-cm from a converging lens having a focal length of 18.0 cm.

4. Determine the image distance and image height for a 4.0-cm tall object placed 12.0-cm from a converging having a focal length of 18.0 cm.

5. A magnified, inverted image is located a distance of 32.0 cm from a converging lens with a focal length of 12.0 cm. Determine the object distance and tell whether the image is real or virtual.

6. **ZINGER:** An inverted image is magnified by 2 when the object is placed 22 cm in front of a converging lens. Determine the image distance and the focal length of the lens.

7. A diverging lens has a focal length of -12.8 cm. An object is placed 34.5 cm from the lens's surface. Determine the image distance.

8. Determine the focal length of a diverging lens that produces an image that is 12.9 cm from the lens (and on the object's side) when the object is 32.4 cm from the lens.

9. A 2.85-cm diameter coin is placed a distance of 31.4 cm from a diverging lens that has a focal length of -11.6 cm. Determine the image distance and the diameter of the image.

10. The focal point is located 20.0 cm from a diverging lens. An object is placed 12.0 cm from the lens. Determine the image distance.