Name: ____________________

Skill Sheet 17.1A — The Law of Reflection

The law of reflection works perfectly with light and the smooth surface of a mirror. However, you can apply this law to other situations. For example, how would the law of reflection help you win a game of pool or pass a basketball to a friend on the court?

In this skill sheet you will review the law of reflection and perform practice problems that utilize this law. Use a protractor to make your angles correct in your diagrams.

1. What is the law of reflection?

The law of reflection states that when an object hits a surface, its angle of incidence will equal the angel of reflection. This is true when the object is light and the surface is a flat, smooth mirror. When the object and the surface are larger and lack smooth surfaces, the angles of incidence and reflection are close but not always exact. Nevertheless, this law is very helpful in performing activities like bouncing a ball to someone or in playing pool.

1. When we talk about angles of incidence and reflection, we often talk about the normal. The normal to a surface is an imaginary line that is perpendicular to the surface.
   a. Draw a diagram that shows a surface, with a normal line, and a ray of light hitting the surface at an angle of incidence of 60 degrees.

   b. In the diagram above, label the angle of reflection. How many degrees is this angle of reflection?

2. Light strikes a mirror's surface at 30 degrees to the normal. What will the angle of reflection be?

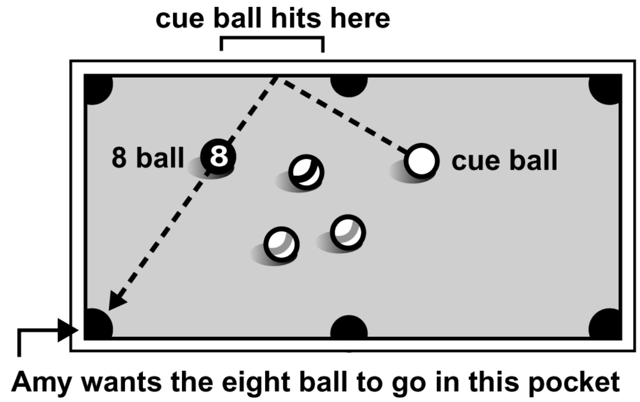
3. The angle made by the angle of incidence and angle of reflection for a ray of light hitting a mirror is 90 degrees. What are the measurements of each of these angles?

4. In a game of basketball, the ball is bounced (with no spin) toward a player at an angle of 40 degrees to the normal. What will the angle of reflection be? Draw a diagram that shows this play. Label the angles of incidence and reflection and the normal.

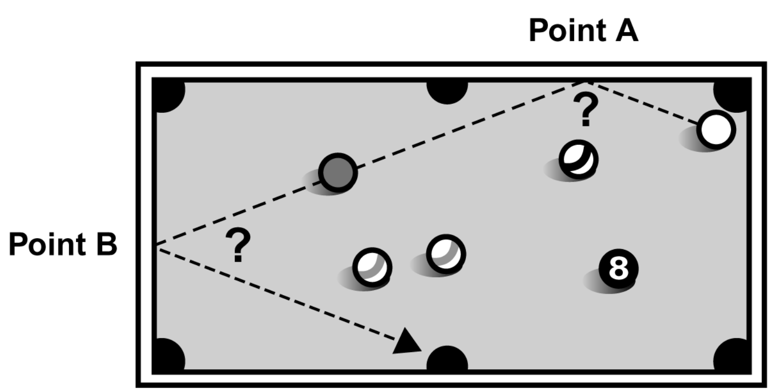
2. Playing pool

Use a protractor to figure out the angles of incidence and reflection for the following problems.

1. Because a lot of her opponent's balls are in the way for a straight shot, Amy is planning to hit the cue ball off the side of the pool table so that it will hit the 8-ball into the corner pocket. In the diagram, show the angles of incidence and reflection for the path of the cue ball. How many degrees does each angle measure?



2. You and a friend are playing pool. You are playing solids and he is playing stripes. You have one ball left before you can try for the eight ball. Stripe balls are in the way. You plan on hitting the cue ball behind one of the stripe balls so that it will hit the solid ball and force it to follow the pathway shown in the diagram. Use your protractor to figure out what angles of incidence and reflection are needed at points A and B to get the solid ball into the far side pocket.



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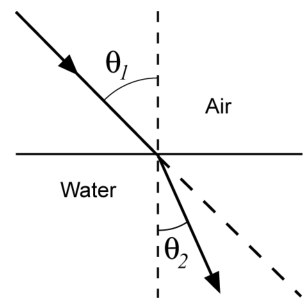
Skill Sheet 17.1B Refraction

When light rays cross from one material into the other they bend. This bending of light rays is called **refraction**. This phenomenon is very important and useful. All kinds of optics, from your glasses to your camera lens to your binoculars use this principle. In this skill sheet we will understand this phenomenon and learn how to calculate the actual amount of bending as light goes from one material into the other. All we need to know is the properties of the materials and some simple geometry.

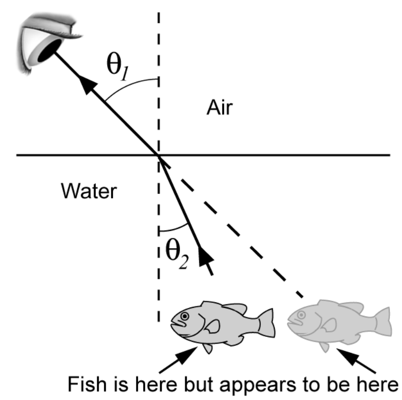
1. Introduction to refraction



The principle is illustrated on the diagram. In this case we have air and water as the two materials where light travels. A light ray making an angle θ_1 with the vertical hits the water surface. This ray will enter the water at a different angle from vertical θ_2.

Once we know the path that a light ray takes as it enters the water we also have the solution of the problem where the light ray starts from the water and enters the air.

A fish in the water does not appear to be where it actually is. A light ray that leaves the fish enters our eyes after it as been refracted as shown on the diagram. So, if you are a hunter trying to spear this fish you better know about this phenomenon or the fish will get away. Very early humans realized this phenomenon and adjusted their aim with great success.



Here are two questions to consider:

1. Why does the light ray bend as it crosses from one material into another?
2. How much does it bend?

The answer to the first question is related to the properties of the materials. For the purpose of refraction, the property of the material is represented by a number called the "index of refraction" which is represented by the symbol n. We call n_i the index of refraction of the material from which the ray is coming (incident material) and n_r the index of refraction of the material to which the ray is entering (refractive material). Also the corresponding angles are called θ_i and θ_r. The general rules of thumb are:

- If n_i is less than n_r, then θ_r is less than θ_i.
- If n_i is greater than n_r, then θ_r is greater than θ_i.

The answer to the second question is provided by Snell's law which describes the relation between n_i, n_r, θ_r, and θ_i.

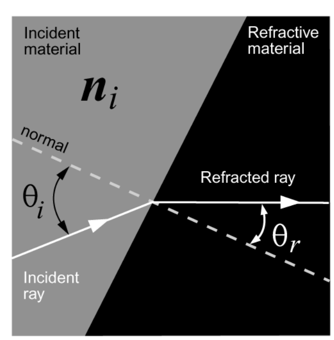
In working with this formula, the incident and refractive angles are measured from the normal to the surface. Also assume that the surface between the two materials is smooth.

Snell's law

Angle of incidence (degrees) — Angle of refraction (degrees)

$$n_i \sin\theta_i = n_r \sin\theta_r$$

Index of refraction of incident material — Index of refraction of refractive material



2. Example problems

Solve the following problems using Snell's law. The first problem is done for you as an example.

1. Air has an index of refraction equal to 1.0 and glass has an index of refraction equal to 1.5. Light travels from air into glass with an angle of incidence $\theta_i = 25°$. What is the refractive angle θ_r?
   We can solve for θ_r from the relation: $n_i \sin\theta_i = n_r \sin\theta_r$

   $$\sin\theta_r = \frac{n_r}{n_i}\sin\theta_i = \frac{1.0}{1.5}\sin 25° = \frac{1.0}{1.5}(0.423) = 0.282$$

   and the angle θ_r is given by the inverse sine of 0.285: $\theta_r = \sin^{-1}(0.282) = 16.38° = 16°$
2. Light travels from glass into air. The incident angle $\theta_i = 30°$. What is the angle of refraction?

3. Light travels from air into glass. The angle of refraction is $\theta_i = 30°$. What is the angle of incidence?

4. Light travels from air into diamond. The index of refraction for diamond is 2.4 and the incident angle $\theta_i = 30°$. What is the angle of refraction?

5. If the incident and refraction angles are 30 degrees and 45 degrees, respectively, which material has the larger index of refraction and what is the ratio of the refraction indices?

6. Air has an index of refraction equal to 1.0 and glass has an index of refraction equal to 1.5. Light travels from glass into air. Calculate the incident angle for which the refractive angle equals 90 degrees.

7. When the angle of refraction becomes 90 degrees we have a very special and interesting situation. The incident angle that corresponds to this case is called the *critical angle*. When the incident angle becomes greater that the critical angle the incident light will now be reflected at the surface. This is called total internal reflection. Calculate the critical angle (the angle of incidence) as we did on problem 6 for light travelling from diamond to air.

8. Calculate the critical angle of refraction for the water-air interface. The index of refraction for water is 1.33.