1. Using a ruler, draw a diagonal line AD, representing a boundary between deep and shallow water. Make two marks on that line about 4 to 8 cm. apart, and label them "B" and "C" so that the four points are arranged alphabetically on the boundary line.
   a. On the "deep" side of the boundary draw two parallel lines, EB and FC, so that angle DBE is roughly 60 degrees. These two lines represent waves in the deep water.
   b. On the other side of the boundary, make lines BG and CH, representing the same two waves extended into the shallow water. Because the wavespeed in the shallow water is less than in the deep water, these two parallel lines must be closer together than the first pair. Therefore angles ABC and BCH must be visibly _____ than 60 degrees.
   c. Label angles "d" and "s". (The deep-water angle is “d”, and the shallow-water angle is “s”.
   d. Make a dotted line from point C to line EB so that the dotted line is perpendicular to EB.
   e. Make a similar dotted perpendicular from point B to line CH.
   f. We have already chosen names and symbols for the lengths of these two dotted lines. Define those symbols here and use them to label the dotted lines.

2. Now use a compass and ruler to construct a new diagram showing what the waves would look like if we made angle "d" smaller. Use the hints below:
   a. First draw a new boundary line and label it AD.
   b. Draw a wave like FC. Remember to make angle d smaller than it was in #1.
   c. Use your compass to make a circle centered on point C, with a radius equal to the deep-water wavelength.
   d. Construct line EB parallel to FC, and the proper distance from DE. (This line must be _____ to the circle.)
   e. Use your compass to make a circle centered at point B, with a radius equal to the shallow-water wavelength.
   f. Construct a new line CH. In order for this line to be the right distance from point B, it must be ____ to the second circle.
   g. Construct a new line BG, parallel to the new CH.

3. Is the new diagram unique? In other words, is it the only diagram possible with that particular value for angle DBE and with that particular pair of wavelengths? ____ To find out, try to construct a *different* diagram with the same angle DBE and the same wavelengths.

4. Use a different color to draw arrows onto the waves in each diagram to show the direction of the wave motion in each region.
   a. The angle between the arrow and the wave must be ____ degrees.
   b. Is it ever possible for the arrows on both sides of the boundary to point toward the boundary? ____ -Is it ever possible for the arrows on both sides to point away from the boundary? ____
   c. What must you do if the arrows on any of your diagrams point in "impossible" directions, as explained in 4b?

5. When one of the angles (s or d) is changed without changing the depths or frequency, does the other angle always change too? ____

6. Given two wavelengths and one angle, can you predict the other angle by using only a pencil, a compass and a ruler? ___ Can you make a fairly accurate prediction even without the compass? ____ (You should record the procedure for future reference.)

7. Does your prediction method have any limitations? In other words, are there any special cases in which it won't work? ____ *If so, you must describe them clearly.*

1. Refer to the diagram that you saved from page 149, describing a pair of straight waves crossing a straight boundary between regions with different wavespeeds.) Think about what must happen if you change the angles between the waves and the boundary *without* changing the frequency or wavespeeds:
   a. Which sides of the triangles must change, and which sides cannot?
   b. Does the wavelength ratio change? ____

2. What symbol did you choose to represent the length of the hypotenuse shared by the two right triangles? __
   a. Divide the numerator and the denominator of the wavelength ratio by that length. Does that alter the value of the ratio? ___
   b. Which trigonometric function relates the labeled angle to the wavelength and hypotenuse in these triangles? ____
   c. Use 2b to write two equations, one for each triangle. (Use the symbols already chosen.)
      _____ = _____ ÷ ___ ____ = ____ ÷ ____

3. How must the sine ratio be related to the wavelength ratio? **sin(d)/sin(s) =** ____

4. How is the sine ratio related to the wave speed ratio? _____=_____

* 5. Does the sine ratio change when the angles are changed? Is there anything that must not be changed when the angles are changed in order to make this conclusion valid?

6. The conclusion in #4 was first stated by a Dutchman named Willebroard Snel. Some authors prefer to spell his name with a double "L", but Willie often used only one. People were not so fussy about spelling in those days.
   a. Is Willie's discovery a physical law describing the behavior of matter, or is it a geometrical theorem? ____
   b. Is is always correct, or is it only sometimes true? _____

7. Suppose s = 30 degrees, d = 45 degrees, the shallow-water wavelength is 2.0 centimeters, and the deep-water wave speed is 20 cm/sec. Use that information with the principles that your have just discovered to answer the following questions. If the information is insufficient, then say so.

   a. Determine the deep-water wavelength.

   b. Determine the shallow-water wavespeed.

   c. If s is increased to 40 degrees, what will be the new d value?

   d. Are the waves crossing from shallow water into deep water, or from deep to shallow?

   e. Now suppose the waves are generated in the shallow region and are crossing over into the deep region. Angle "s" is gradually increased. Before it reaches 50 degrees, something strange and different happens. Describe that effect.

   f. What must happen to the waves after that critical angle has been exceeded? They cannot simply disappear, because they carry energy.