1. Prepare a cylindrical tube that is open at the top and partly filled with water. Hold a vibrating tuning fork over the open end and adjust the water level until a loud "resonance" is heard. Measure the length of the air column from the open end down to the water level. Repeat the whole process a few times to see how precise these measurements are.

2. Find another air-column length that also produces resonance at the same frequency. Measure that length precisely, and then see if there are any other resonant lengths between the two that you have measured.

3. Adjust the air column to the shortest resonant length.
   Blow across the end of the tube as you would when making a tone on a flute or a bottle.
   a. How does the pitch of this sound compare with the pitch of the tuning fork?
   b. What kind of wave motion in the pipe may account for these resonances? (See RS XVI.)

* 4. Figure out how many "humps" there must have been in each of the standing wave patterns you observed in 1 & 2. (Use 4 & 5 on RS XVI or 8d on page 138.) Explain your logic carefully. Illustrate with sketches.

* 5. Make a conclusion about the types of reflection occurring at the ends of the air column.

* 6. Explain at least two ways to determine the hump length from the measurements made in 1 & 2. Explain how the uncertainty will be determined in each case.

* 7. Use #2 on RS XV with the frequency stamped on the tuning fork to determine the speed of sound in the pipe in SI units. Remember to show how that speed and its uncertainty estimate are obtained. Also remember that the wavelength is NOT the same as the hump length.

8. Use several different tuning forks to measure the shortest resonant lengths at several different frequencies. Make a data table and a graph showing how the resonant **length** depends on the **period.** Draw two reasonable lines on this graph. *The origin is not necessarily a data point.*

* 9. The wave speed can be determined from this graph.
   a. Explain how.
   b. Compare the result with the one obtained in #7. *Remember to explain your uncertainty estimates.*
   c. Is this method more precise than the one in #7? (Please explain your opinion.)

* 10. As nearly as you can tell by ear, does the speed of sound in air depend upon frequency? *Describe your evidence.* -How do sound waves compare in this respect with the transverse waves that you observed on wave springs and guitar strings?

* 11. When you made standing waves on a stretched spring on page 136 there was some motion at the end that you were shaking. That end was therefore not exactly a node.
   a. Sketch a two-humped standing wave pattern showing this effect.
   b. Assume that the amplitude of the hand motion is one-_____th of the standing wave amplitude, and that the spring length is _____ meters. (Choose any reasonable numbers.)
   c. Explain why the hump length is not exactly half of the spring length in this case.
   d. Using the values that you chose in 11b, calculate the true wavelength for this example. Show your method clearly.

12. Could a similar "end effect" exist in the sound wave experiment? ___
   * In what way would it affect the graph that you made for #8?

* 13. Look closely at your graph. Decide whether it displays the symptoms describe in 12.

* 14. Did the two calculated hump lengths agree back in #7? If not, which one is more likely to be correct, and why? Also, what can you conclude from this observation?

Imagine an air-filled pipe with a piston fit into one end. The piston is struck with a mallet, causing it to start moving forward with a steady velocity which we shall call "V_p". After a short time interval ("___") there will be a region of compressed air in front of the piston. That is a sound wave. The air molecules in that region must move with the same velocity as the piston. But as the wave moves forward, the amount of air in it must increase continuously as more and more air is "piled up" in front of the piston. The forward boundary of the compressed-air region, called the "wave front", must move forward faster than the piston. We shall use "V_w" to represent the velocity of the wave front.

1. Write a formula for predicting how far the wavefront advances during a given time interval. (Use one of the velocity symbols defined above.) $\mathbf{D_w}$ **=** ________

2. Write a similar formula predicting how far the piston moves during the same time interval: $\mathbf{D_p}$ **=**

3. Let "A" represent the cross-sectional area of the pipe. Use that symbol and the ones above to write a formula for the volume of the compressed air: **Volume =** _____

4. Write a formula for the volume of that same batch of air *before* it was compressed: ____

5. Write a formula for the air's fractional change in volume. (That's the change in volume divided by the original volume.) *Simplify the formula in any way that you can.*

6. Define a new symbol to represent the original density of the air, before compression: _____
   a. Use it to express the mass of the moving compressed air: **m =** ______
   b. Express the momentum of that air in terms of the density and other symbols defined earlier: momentum = _____

7. How must that momentum be related to the impulse delivered to the air by the piston? ____ (See pages 53 & 54 or Review Sheet V.) Write this relationship in equation form: ____ = ______

8. How can you use the air pressure in front of the piston and the cross-sectional area to calculate the unbalanced force exerted on the air by the piston? **F =** ____

9. Use equation 8 to eliminate the "F" from equation 7: _____ = _____

10. The ratio of the air's fractional change in volume to its change in pressure is called the "compressibility" of the air.
    a. Choose a symbol to represent the compressibility of air: ___
    b. Use it to simplify equation 9: _____ = _____
    c. Solve for the wavespeed: $\mathbf{V_w}$ **=** _______

11. On the previous page you measured the speed of sound-waves in an air-filled pipe. Copy that result here. *Don't forget to give its estimated uncertainty or range, with units!*

12. Anyone who has studied chemistry in high school remembers that one "mole" of an ideal gas occupies 22.4 liters at standard temperature and pressure. Air is about 20% oxygen (32 grams per mole) and 80% nitrogen (28 grams per mole).
    a. Calculate the mass of one mole of air. ______
    b. How many liters are there in one cubic meter? _____
    c. Calculate the density of air in SI units. (Compare with the estimates on pages 56 and 65.)

* 13. Use the data from #11 & #12 to calculate the compressibility of air. Show how you do it.

* 14. Use the ideal gas law to predict the compressibility of air. Compare this theoretical result with the empirical one found in #12.