1. Imagine a long spring being used in a standing wave experiment like the one on p. 142. Choose any reasonable values for the following quantities: **Length = ___ m.** **Number of humps = ___.** (A "hump" is the part of a standing wave that is between two adjacent nodes.)
   a. Use that information to calculate the "hump length, i.e. the distance from one node to the next. __ _
   b. How many humps are there in one full cycle of a sine curve? ____
   c. Use 1a and 1b to calculate the wavelength in SI units. (Remember to define your symbols.)

2. If you were able to do 1c, then you know how to calculate wavelength from spring length and one other piece of information. Write that formula, define your symbols, and show that the units match.

3. For *any* periodic wave, how can wave speed (in meters per second) be calculated from frequency (in waves per second) and wavelength (in meters per wave)? **Speed = ________**
   (This "wavespeed formula" is being saved in # __ on RS ____.)

4. Use data from the standing wave experiment on page 136 to make a data table showing how wavelength and wavespeed are related to frequency. Remember to give names, units and uncertainty estimates, and to *explain* those estimates. (Use 2 & 3 above.)

* 5. Does spring wave speed depend on frequency? -Can you make a similar conclusion about guitar string waves? Explain your experimental evidence.

* 6. Is #5 a theory, or is it an empirical discovery? -Is there any reason to believe that the same conclusion will be valid for other kinds of wave motion in other media? If so, please explain.

7. A long uniform spring is cut into two unequal segments which are stretched with equal tensions:
   a. How will wave speeds on the two segments compare? ____
   b. Is it correct to say that wave speed depends on the spring's mass? ___ --on its length? ____

8. A guitar string's tension can be adjusted, altering the frequency or "pitch" of its vibrations.
   a. What happens to the frequency of the string's vibrations when you increase its tension? ___
   b. What happens to the wave speed when the tension is increased? _____

9. The six strings on a guitar have approximately equal tensions, but you can easily hear that their standing wave frequencies are not equal. That tells you something about their wave speeds.
   a. Which strings have the higher wave speeds: the thin ones, or the thick ones? ____
   b. The mass-to-length ratio for a wave spring or guitar string is called **"linear density"**.
      In SI units regular density is measured in kg per ____, but linear density must be in ___ per ___.
   c. Is guitar string wave speed related to linear density? _____
   d. When we increase the linear density the wave speed ___creases.

10. According to 7-9, what *variables* must appear in a formula for *PREDICTING* wave speed on strings or springs? (Give names *and* symbols.) *Try not to contradict #5.* -Also explain what *exponents* must be on those variables to make the units balance.

11. The "mode number" of a standing wave is its number of humps. Use the clues above to create a new equation relating standing wave frequency to mode number. Remember to define your symbols.

12. Notice that there is one symbol in the equation 11 which may represent a variable **OR** a constant, depending on the medium and the type of wave.
    a. Which symbol is that, and what does it represent? ______
    b. If that quantity is independent of frequency, then the graph of frequency vs mode number will be a ______ line through the _______.
    c. If that quantity *does* depend on frequency, the graph will be a _______ line ________ the origin.

13. Look at the graph of f vs N that you made for page 136.
    a. Describe its shape.
    b. What new conclusion about wavespeed can you make? (Use #12.)
    c. Does #4 on this page support this conclusion?

1. Sketch a round-topped pulse travelling to the right on a wave spring. Make two marks close together near the top of the pulse. Label them "A" and "B". If arc AB is short enough, we can say that it is approximately circular. The "center of curvature" of a circular arc is the place where you stick the point of a compass when you draw the arc. Make a dot to show the approximate location of your arc's center of curvature and label it "O".

2. Imagine that you are running along beside this pulse, with the same velocity as the pulse. In your frame of reference the spring seems to flow like a river along a curved path but the pulse appears to be ______. (stationary, moving) If the velocity of the pulse relative to the spring is "v" then the velocity of the "flow" relative to the runner must be ___.

3. Remember that the path of flow between A and B is a circular arc. Some centripetal force is needed to keep that moving mass on that circular path. Let "m" represent the mass of the segment between A and B, and let "R" represent the radius of curvature. (R = OA = OB) Using #7 on RS VII, show how the centripetal force can be calculated from m, v, and R. **F =** _____

4. Remember that the spring is under tension, so that segment AB is being pulled to the left and to the right with nearly equal forces. The two forces are not exactly opposite in direction, however, because the segment is *slightly* curved between A and B.
   a. Along what lines through points A and B must these two force vectors be drawn?
      (Radius? Normal? Tangent? Vertical? Horizontal? Chord AB?)
   b. The sum of those forces must point toward the _______ of the arc, i.e. in the _________ direction.
   c. Draw that vector sum, being careful not to change the directions of the vectors. (The angle between the two tensions must be very _____.)
   d. Label the tensions with the letter "T" and label their sum with an "F".
   * e. Prove that the force triangle in 4c is similar to triangle AOB.
   f. If angle AOB is small then line AB has approximately the same length as arc ___.
      (That approximation can be improved without limit by making the arc still shorter.)
   g. Use the similar triangles to discover the equation relating F, T, R, and length AB. ____ = _____

5. Use equation 3 to eliminate the "F" from equation 4g. Then you will have an equation relating the wavespeed to measurable properties of the medium. Notice that the equation is quadratic, so it has *two* solutions with opposite _________s. *Please remember to use that fact in #6.*

6. The "linear density" of a long thin object like a wave spring or guitar string is the quotient obtained when you divide its _________ by its ________. (See RS XVI.)
   a. How does the linear density of the segment compare with the linear density of the entire spring?
   b. Choose a symbol to represent linear density: ____ Use it to simplify the wavespeed formula discovered in #5. Remember to see if the units balance.
   c. A copy of this formula is being saved in # __ on RS __.
   d. Tapping a clothesline causes a wave to travel from one end to the other. Suppose the line is 20 m. long, the tension is 35 N, and the linear density is 0.052 kg/m. How fast will the wave travel?

* 7. Measure the tension and linear density of a stretched wave spring. Also measure its wavespeed as you did on page 136. Find out if the new wavespeed formula (#6 on this page) agrees with those results. Remember that no conclusion is possible without explanation of uncertainty estimates.

8. A certain wavespring has a tension of 25 N when stretched to a length of 2.5 m.
   a. The wave speed on this spring is 15 m/sec. Calculate the mass of the spring.
   b. Calculate the lowest standing wave frequency on this spring if it is held rigidly at each end.
   c. At what other frequencies will standing waves be possible?
   d. What frequencies are allowed if one end is held in position but the other end is free to move up and down? (Use #5 on RS XVI.)