Physics Lab 20: Standing Waves and Doppler Shift

Goals: Improve communication, teamwork, and note-taking abilities; Add waves graphically; Produce standing waves on springs; Observe standing waves on strings and determine a relationship between tension in string and wave speed; Observe standing waves of sound and estimate the speed of sound in air; Watch videos/perform video analysis to observe Doppler Shift and verify/apply Doppler Shift equations; Use a simulation to observe wave interference in two dimensions to prepare for next week's work; Find fun with physics phenomena.

Equipment: Computer; Slinky; Demo Station: sound tube with fixed speaker, movable microphone, function generator, oscilloscope; Demo Station: string between two posts and over pulley with mass set, mechanical oscillator, function generator & amplifier.

Groups & Lab Notebook: You will be assigned to lab pairs (there may be one lab triple). Reminder: your physics lab notebook should reflect your learning and your engagement, and should serve as a ***stand-alone*** representation of what you did and what you learned.

Part 0: Overview

Today's lab consists of a series of linked activities through which you will create/observe various types of phenomena associated with traveling waves and standing waves through hands-on activities, graphing, and analyzing videos.

Part 1: Making Waves I

1. Open the Desmos calculator **https://www.desmos.com/calculator/mckpcwsc5n**, which is similar to one you worked with previously. Under Graph Settings (the wrench icon), turn on Projector Mode. Click the circle in line 3 to turn on the graph of that wave. Start the animation by pressing play in line 1. Do you see a wave moving to the right? Given the harmonic wave function in line 3, does that direction make sense?
2. Pause the animation, and re-set to time $t = 0$. Use the slider in line 2 to set $f = 2$. Does the change in the shape of the wave make sense? You've doubled the frequency, so what should happen to the wavelength, assuming the wave speed is constant? Is that what you saw? Start the animation: is the wave still moving to the right at the same speed as when $f = 1$? If you like, you can try for other values of f.
3. Pause the animation. Re-set t to 0 and f to 1. Click the circle in line 3 to turn that graph off, and click the circle in line 4 to turn that graph on. Note that the only difference between line 3 and line 4 is the positive sign. What effect will that have? Turn on the animation to confirm.
4. Pause/re-set t to 0. Make sure lines 3 and 4 are turned off, and turn on line 5. Note that line 5 is the sum of the right-moving wave from line 3 and the left-moving wave from line 4. So we are adding a right-moving traveling wave to an identical but left-moving traveling wave. What kind of wave do we get? Turn on the animation to confirm.
5. Pause/re-set t to 0. <u>Change the graph display so that the x-axis is $0 \le x \le 0.5$</u> (under Graph Settings). With t still held at 0, adjust f from 1 to 2 to 3 to… What happens to the shape of the graph? What does doubling the frequency do to the wavelength? Tripling the frequency? Etc. If you like, you can do this while running the animation.
6. Now, make some standing waves. Obtain a "short" slinky. Each partner should hold one end of the slinky, and you should stand far enough apart that the slinky has a reasonable amount of tension in it. Move into the hallway if you would like more room. One person should hold their end of the slinky fixed. The other person should move their end of the slinky vigorously in an oscillatory up and down motion, trying to make a transverse standing wave. Try to make a standing wave with the longest wavelength possible (like the first standing wave you saw graphed). Estimate the frequency of oscillation (in Hz). If you call the distance between partners (and thus the length of the slinky) L, then the wavelength of this standing wave should be $2L$.
7. Reverse roles so that the other person holds their end fixed and the partner moves their end to get the same standing wave pattern; this is so both partners get practice generating standing waves on your slinky.
8. Standing in the same positions (so that you keep the same length L of the slinky), increase the frequency of oscillation until you get a different standing wave pattern. Try to get the second standing wave you saw graphed; if you do, then the wavelength of this standing wave should be L.
9. Keep increasing the oscillation frequency until you get another standing wave; estimate the frequency, and note the wavelength (in terms of L). Do this until you have produced a total of 5 different standing wave patterns (including the ones you made in 3. and 4.
10. Summarize your results in a table of frequency (in Hz) and wavelength for that frequency (in terms of L). Also include a sketch of the standing wave in your table. Do you notice a pattern? What pattern?
11. Optional Challenges (perhaps do at end if time):
    I) Try to make the highest frequency standing wave among your classmates.
    II) Try to make a standing *longitudinal* wave.

Part 2: Making Waves II.

1. Return to the Desmos calculator you used in Part 1. Re-set t to 0. Turn off lines 3, 4, 5. **Make sure the graph display is limited to $0 \leq x \leq 0.5$.**
2. Turn on lines 7 and 8, and run the animation. You should see animations of the two lowest modes of a standing wave, individually plotted on the same graph. We know that waves in the same region of space will interfere via the superposition principle. What do you think the superposition of these two modes would "look" like?
3. You can attempt to see for yourself using your slinky. Each partner should hold one end of the slinky, as you did in Part 1. One of you should move your end up and down periodically until you get a standing wave of the lowest harmonic as you did previously. Pay attention and remember the rate at which the end was moved up and down, and then stop moving that end. The other partner should move their end up and down periodically to obtain the next harmonic of standing wave; again, this partner should remember the driving rate they used.
4. Now, BOTH partners should drive their end: one with the frequency of the first harmonic, and the other with the frequency of the second harmonic. What do you observe? Write down some comments about your observations and your experiment. Include some sketches or at least a written description of the motion you observe.
5. Return to your Desmos calculator. Re-set to $t = 0$. Turn off lines 7 and 8. Turn on line 10, and run the animation. (If it helps you to visualize, you may turn lines 7 and 8 back on, along with line 10.) Does what you see resemble what you tried to make in the previous step?

Part 3: Demonstration Station I: Standing Waves on Strings. We'll collect data as a class; if you reach this part of the lab before the class demonstration, skip ahead to Part 5. For this part of the lab, we have a speaker hooked up to a function generator (and amplifier) tied to an elastic string; the string's other end goes over a pulley and is attached to some mass.

1. We'll adjust the driving frequency to make different standing waves.
2. Collect data of number of antinodes, nodes, frequency, and wavelength. Make sure to sketch pictures of each of the standing waves. Organize this information in a table. What patterns do you notice?

Part 4: Demonstration Station – Wave Speed in Strings and Tension. We'll collect data as a class; if you reach this part of the lab before the class demonstration, skip ahead to Part 5. For this part of the lab, we have a speaker hooked up to a function generator (and amplifier) tied to an elastic string; the string's other end goes over a pulley. That end of the string has masses hanging from it, so we can change the mass and thus change the tension in the string.

1. We'll adjust the frequency and make a particular standing wave for a particular tension, measuring the frequency and wavelength of the standing wave.
2. We'll increase the tension, adjust the frequency to get the same harmonic as in the previous step, and measure the frequency and wavelength. We'll repeat this several times.
3. Organize in a table data on tension, frequency, and wavelength (this should be fixed for particular harmonic as it is determined by string length).
4. **[Complete this at the end or after class.]** Recall that wave speed equals frequency times wavelength. Make a plot of tension vs. wave speed (what goes on what axis?). See if you can determine a qualitative relationship between tension and wave speed. See if you can determine a quantitative relationship between tension and wave speed (hint: try a power law fit). How does this result compare to that presented in your text? Discuss sources of deviation, if any.

Part 5: Demonstration Station – Standing Sound Waves

1. If this station is too crowded, move on and come back to it. You will work with an instructor at this station, located in the side room. This station consists of a tube with a speaker fixed at one end and a movable end with an embedded microphone. The speaker is driven by a function generator, and the microphone signal displayed on an oscilloscope.
2. Starting with the microphone near the speaker, slowly increase the length of the tube. Observe the frequency and amplitude of the signal on the o-scope. In addition to seeing changes on the o-scope, also listen for changes.
3. Did the frequency depend on the length of the tube? Does this make sense? Why did the amplitude change with the length of the tube (e.g. why did you observe resonances at different tube lengths)?
4. Record the frequency of the sound. Also record the tube lengths (microphone positions) associated with resonances (where the amplitude is highest).
5. Recall that wave speed equals frequency times wavelength. Determine the speed of sound in air.

Part 6: Doppler Shift (based on Experiment 5 Doppler Effect from Advanced Physics with Vernier – Beyond Mechanics)

0. All movies are in the program share, Handouts: Physics: Physics Labs: Lab 20.
1. Open the movie Car Horn with whatever media player is on your computer. Make sure your computer volume is on but not too loud, and play the movie. Confirm that you hear what was discussed in class about frequency changes as the car is moving towards the observer, then away from the observer.

2. Launch LoggerPro. Using Insert, Movie, find Ripple Tank 1. View this movie, either by stepping through using the play slider or changing the playback speed (right click on the movie, choose Movie Options, reduce Speed to 0.1x).
3. Turn on the Video Analysis Tools by clicking on Enable/Disable video analysis tools in the lower right hand corner of the movie playback window. Determine the speed of the waves by tracking one particular wavefront (you may want to skip some intervening frames so you're not clicking on every frame. Do this under Movie Options, using Advance the movie. You may also need to Override the frame rate – the frame rate is in the first frames of the movie. The first frames of the movie also give you info to set the scale).
4. Determine the frequency of the waves by watching a stationary point on the screen and counting the number of waves that pass by in a given time. Note that the bright rings represent crests of the water waves.
5. Determine the wavelength of the waves. You may find using the Photo Distance tool useful.
6. Verify that the wavelength, frequency, wave speed relationship holds. If not, check your measurements.
7. Insert the Movie Ripple Tank 2. In this movie, the source is moving. Watch this movie, again in slow motion or frame by frame. What is noticeably different compared to when the source is stationary?
8. Define "in front of the source" as along the line the source is moving and to the right of the source, and "behind the source" as to the left of the source, also along the line. Determine the wave speed, the speed of the source, and the frequency and wavelengths of the waves in front of the source and behind the source. Verify that the wavelength, frequency, wave speed relationship holds for the "in front" waves and the "behind" waves. If not, check your measurements.
9. Your text gives two different formulas for the Doppler Shift formula: one for moving source and one for moving observer; you still have to use judgement about choosing between + or – in either formula . A more compact single equation is:

$$\frac{f_o}{f_s} = \frac{v \pm u_o}{v \pm u_s}$$

   where v is the wave velocity with respect to its medium, f_s is the frequency of the source when at rest with respect to the medium, u_s is the speed of the source with respect to the medium, u_o is the velocity of the observer with respect to the medium, and f_o is the frequency the observer, well, observers. You still have to use your judgment to choose the sign in numerator and/or denominator. Discuss with your lab partner to see if you understand how to do this; please ask Krishna for clarification.
10. Verify that your results from Ripple Tank 2 are consistent with the Doppler Shift formula for both the in front case and the behind case.
11. An analysis of the Car Horn video from before shows that as the car approaches the observer, the frequency is 610 Hz, and as the car recedes from the observer, the frequency is 546 Hz. Use these values to determine the speed of the car, then perform video analysis of the car in Car Horn to determine its speed. Compare the values obtained in each of these methods.

Part 7: Wave Interference. This is set-up for next week. If you don't complete today, then consider this as part of your reading assignment for next week.

0. Use the Chrome browser. When launching the PhET simulation, do not accept any prompts to update Java but accept other prompts to run the simulation.
1. Run Wave Interference at **https://phet.colorado.edu/en/simulation/wave-interference**. Enlarge the window so that it fills your screen and make the simulation as large as possible as well.
2. Start in Water with just one dripping faucet (should be the default). Increase the amplitude all the way, and change the frequency to be about halfway on the scale. Turn on Two drips. What do you observe? In particular, can you observe the nodal lines?
3. One at a time, change the amplitude, frequency, and spacing, noting the effect of each on the interference pattern, and particularly on the spacing and location of the nodal lines. Summarize your findings.
4. Investigate the Add detector and Show Graph features and see if they reveal anything new to you.
5. Return to One drip. Add Wall; you can change the location, orientation, and length of the wall with the mouse, and remove the wall by right-clicking. Investigate the effects of having a barrier like the Wall. In particular, see if you can make an interference pattern with nodal lines.
6. Remove the wall, and still with One drip, Turn on One Slit. Investigate the effects of changing the Barrier Location and the Slit Width. Were you able to make nodal lines? (Probably not). Summarize your findings.
7. Turn on Two Slits. Adjust frequency, amplitude, barrier location, slit width, and slit spacing until you have an interference patter with clear nodal lines. Why do you get nodal lines with two slits?
8. Investigate the effects on the location and spacing of the nodal lines of changing (one at a time) the barrier location, the slit width, and the slit separation. Summarize your findings.