Physics Lab 22: Wonderful Waves, Fourier Fun, and Making Music

Goals: Improve communication, teamwork, and note-taking abilities; Make complex waves from simple waves and decompose complex waves into simple waves using Fourier analysis; Find fun with physics phenomena.

Equipment: Computers; LabQuest, connecting cables; tuning forks, wine glasses, bottles, instruments.

Groups & Lab Notebook: Lab trios. Lab notebook should serve as a *stand-alone* representation of what you did and what you learned.

Part 1: Getting Started
1. Get in to lab groups of 3. Each lab group should take a table. Log on to <u>both</u> computers at your table. Get <u>one</u> LabQuest from the charging station in the back, connect it to one of your computers, and turn it on. Once on, launch LoggerPro.
2. Under Experiment: Set up Sensors, choose LabQuest. Turn on the Microphone by checking the appropriate box. Close this dialog window.
3. What do you see back in LoggerPro? What are the axes on the graph? What does the meter box measure?
4. The internal microphone on the LabQuest is on the front left hand-side; it's the small rectangular opening. Whistle into the microphone and watch the meter on the screen. Whistle loudly and softly; near and far. What happens to the reading on the meter?
5. Under Experiment: Data Collection, note down the default parameters. You might find that you will want to increase the data collection time by a little bit in some of your later measurements (the default may be just fine); this is where you do that. Close the Data Collection dialog window.
6. While one person whistles a single note steadily into the microphone, the other partners should collect data. Recall that hitting the space bar is the keyboard shortcut to collect data. Start whistling, then collect data; when data collection is done, then stop whistling. Once you have a clean data set, Store Latest Run (under Experiment).
7. Under Data: Data Set Options, choose Run 1 (probably), and rename it Whistle 1.
8. Collect data for a different partner whistling a different note; store a clean data set and rename as Whistle 2.
9. Display both Whistle 1 and Whistle 2 on the graph (they may already be displayed). Can you see a difference?
10. Finally, collect data from two partners, each whistling a different note but at approximately the same volume, at the same time; store a clean data set and rename as Two Whistles.
11. Graph just Two Whistles on its own graph.
12. Save this LoggerPro file with a useful name that includes the names of your group members to the Workspace. Close LoggerPro and then launch it again. **NOTE: YOU WILL HAVE TO TURN ON THE MICROPHONE EACH TIME YOU RE-START LOGGERPRO** SORRY FOR SHOUTING.
13. After every group has completed to this point, your instructor will go over the steps in Part 2 with the whole class. If you are waiting for Part 2 to start, move on to Part 3.

Part 2: Waveform Spectrum Analysis – Curve Fitting and Fourier Analysis
0. If you are waiting for this part to start, move on to Part 3. We will do this as a class, led by the instructor at the front station while your group follows along at your station, repeating what the instructor is modeling.
1. Your instructor will play a computer generator pure 440 Hz tone over the class sound system. Measure this tone using the internal microphone on your LabQuest. Once you have a clean signal, Store Latest Run and rename it 440 Hz.
2. Zoom in on the horizontal axis to display 5 or 6 full periods. Highlight the data, and under Analyze: Curve Fit (there's also an icon shortcut), find Sine, check the button, and Try Fit.
3. This curve fit returns a function $A \sin(Bx + C) + D$. (In this case, the x might be t since the horizontal axis is time, but the default may still be x.) Write down the values plus uncertainty plus units for A, B, C, and D.
4. What are the meanings of A, B, C, and D?
5. Verify that the value of B is consistent with the frequency of 440 Hz.
6. Under Insert: Additional Graphs, select FFT Graph. This will display a Fast Fourier Transform graph of the waveform data you collected. What are the axes of this graph? What else do you notice about it?
7. Hide the 440 Hz data set. Hopefully this will hide the data from the time graph and the frequency graph. Re-set your time graph so its horizontal axis runs from 0 to the data collection time.
8. We'll repeat the previous steps, but this time for 880 Hz.
9. Next, we'll play 440 Hz and 880 Hz simultaneously. Collect data, store a clean data set renamed as Two Tones. Looking at the time graph, what value (if any) might be gained from doing a Sine fit? Do you learn anything from looking at the frequency graph?
10. Finally, we'll play a note from a virtual piano. Collect data, store a clean data set renamed PiaNote. What do you see on the FFT?
11. Save this LoggerPro file with a useful name that includes the names of your group members to the Workspace. Close LoggerPro and when needed launch it again; remember to turn the microphone back on.

Part 3: Complex Waves from Simple Waves, Graphically

0. We've seen that adding together waves of the same frequency but moving in opposite directions results in a standing wave (for example in Lab 20, we saw this both graphically and for physical systems of standing waves on strings and of sound). In earlier parts of this lab, you observe what happens when you add waves of different frequencies by playing different sounds simultaneously. In this part, you will investigate this graphically.
1. On the other computer, open the following Desmos calculator **https://www.desmos.com/calculator/rspcqkcywt**
2. Turn on the f graph, and start the animation by playing t. Do you see a traveling wave with a definite wavelength moving at a constant speed to the right? Does this make sense given the function for this wave?
3. Pause t and re-set to 0. Hide f and show just g. Start the animation by playing t. Do you see a traveling wave with a definite wavelength moving at a constant speed to the right?
4. Pause t and re-set to 0. Hide g. Looking at the two functions f and g, which do you expect to move faster, or do you expect the same speed? Discuss with your group and write down a prediction. Test your prediction but turning on both f and g and starting the animation by playing t. Was your prediction correct? If not, figure out why.
5. Pause and re-set t. We know that because of superposition/interference, f and g will add together in complex ways. Looking at f and g separately, what do you think $f + g$ will look like? Write down your prediction before you display $f + g$, and discuss with your partners. Then, turn on $(f + g)$. Does it match your prediction? If not, figure out why.
6. Hide f and g and leave $(f + g)$. Turn on the animation. What do you notice?
7. If you superposition two waves with different wavelengths, you get "wave packets", a spatial localization of waves, which you can see directly from the animation. Having two different wavelengths usually means you have two different frequencies, which gives you "beats", which is a temporal phenomenon. To "experience" beats, pick a spot on the x-axis (say $x = 0$), and as the animation plays, notice the amplitude variation at that spot. What does amplitude correspond to, for a sound wave? What will this sound like? Discuss with your group and write down a prediction.
8. We'll test this prediction as a class. If you've reached this point before the class demonstration, leave some space.
9. Still on the computer that doesn't have the LabQuest connected, go to Fourier: Making Waves at **https://phet.colorado.edu/en/simulation/fourier** Run this, accept all warnings, but don't update Java if prompted. In this simulation, you can add together different harmonics of a wave in different amounts.
10. Enlarge the window so it fills the screen. The simulation should prompt you to "Drag me", so do what it suggests and observe the graphs. Drag the bar up for positive values and down for negative values (note you can also type directly in the text entry boxes above each bar).
11. Turn on Auto scale and leave it on. Switch between space(x), time(t), and space&time(x,t) under Graph controls: Function of.
12. Add together several higher order harmonics in different amounts and obtain a few interesting patterns.
13. Go back to just having $A_1 = 1$ and all the rest back to 0. Turn on Sound under Sound controls (you may also have to turn on the volume on the computer as well). Launch LoggerPro, turn on the microphone, obtain a clean data set and rename it as A1. Use the FFT to determine the frequency, and record that value. Turn off the Sound (only turn Sound on for purposeful reasons such as recording data).
14. Turn A_1 to zero and set $A_3 = 1$. Determine the frequency, and record it. What is the ratio the frequency of A_3 to A_1?
15. Produce a wave that adds together several harmonics and makes a visually interesting pattern. What does that visually interesting pattern _sound_ like? Obtain the FFT, and also make sure you record the amplitudes you set.
16. Under Preset Functions, choose sine/cosine from the drop down menu. Look and listen (there shouldn't be much new here). Repeat for triangle, square, sawtooth, and wave packet, each time looking at and listening to the waveform. Note that each has the periodicity of the fundamental. What do you notice about the quality of each sound?
17. Switch to the Discrete to Continuous tab. Turn on x-space envelope and width indicators. Minimize the components graph to improve performance.
18. Under Spacing between Fourier components, set k_1 to 2π. Recall that k is the wave number, and $k = 2\pi/\lambda$. What do you notice, particularly in the Amplitude graph and the Sum graph? One at a time, set k_1 to $\pi, \pi/2, \pi/4$, and 0, again observing Amplitude and Sum graphs.
19. Set k_1 to be $\pi/4$, and leave it at that value.
20. Under Wave packet width, set $\sigma_k = 1$ rad/m. Note that you can use $2\sigma_k$ and $2\sigma_x$ to characterize the width of the packet in k-space and in x-space (in position space, this is a way to characterize the width of the wave packet). Record the value for σ_x which you can read right from the Wave packet width box; it should be 1 m.
21. Set σ_k to be about π and record the exact value. What happens to the width of the k graph? To the x graph? Record the corresponding σ_x value.
22. Repeat for σ_k set to about $2\pi, 3\pi, 4\pi$ (again recording exact values) and recording the corresponding σ_x values. Organize in a table. Also note what is happening to the shape of the graphs. What does $\sigma_x\sigma_k = ?$
23. Under Graph controls, select Function of: time(t). Convince yourself whether the behavior of $\sigma_t\sigma_\omega$ is the same or different from $\sigma_x\sigma_k$.

Part 4: Free Play

The remainder of the time is for open-ended investigations related to spectral analysis. Some suggestions are below; do as many as strike your interest that there is time for, or design your own investigation. Have fun!

- If you brought your own instrument(s), determine spectra for various notes in an octave, or notes separated by octaves.
- Determine the spectra for various notes for different instruments from an online synthesizer. The one here seems unobtrusive **http://www.caseyrule.com/projects/piano/** and will allow you to compare the same note played on different instruments and/or obtain spectra from notes on the same instrument.
- There are two wind instruments that can be played by connecting to the lab air supply via a hose. Ask Paul.
- We have tuning forks. Don't strike the tuning forks on tables or hard surfaces. Use a rubber striker, or pull them along your finger to start them vibrating.
- Investigate the different vowel sounds: each person obtains spectra for each vowel; compare different vowel sounds for the same person, and compare the same vowel from different people.
- Investigate the sound obtained by blowing across the top of a bottle. Change the sound by filling the bottle with different heights of water.
- We have wine glasses; if you wet the rim and run your finger along it, you can get the wine glass to "sing".
- Or other investigations along these lines and consistent with the lab focus that you can think of; please consult.

ANALYSIS/LAB NOTEBOOK:

1. For Parts 1, 2, and 3, include in your lab notebook neatly labeled time graphs or frequency graphs (or both when appropriate).
2. For your Part 4 investigations, describe the investigation, include data (particularly graphs), and discuss any analysis you carried out and conclusions you came to.

LAB CLEAN-UP:

- Please put away all borrowed materials neatly.
- Return your lab station or a neighboring station to better condition than you found it.
- Help your classmates straighten up.

LAB NOTEBOOK CHECKS:

- Lab Notebooks are due Week 27 Tuesday May 15 by 9am to Krishna's office Lab 2 3255.
- Notebooks will be checked for evidence of engagement and attempts at completion.

FINAL LAB DEEP CLEAN:

- Details to be announced.
- Tentatively scheduled Week 29 Wednesday May 30 at 9 am.

Schedule Weeks 26 – 29

Monday	Tuesday	Wednesday	Thursday
9 – 10 Math, Phys Quiz	9 – 12 Project	9 – 10 Phys	9 – 10:30 Chem
10:15 – 11:15 Phys		10 – 12 Phys/Math Workshop	10:30 – 11:30 Project
11:30 – 12:30 Math			11:30 – 12:30 Break/Check-in
12:30 – 1:30 Break	12 – 1 Break/Check-in	12 – 1 Check-in	12:30 – 2:30 Project
	1 – 1:30 Chem Quiz		
1:30 – 3:00 Chem	1:30 – 2:30 Math		
	2:30 – 4 Math Workshop		