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# Acoustic experiments

Student version

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## Acoustic experiments

### Motivation

Not many of us have experienced absolute silence because sounds are literally everywhere around us. Besides being our everyday company acoustic phenomena have a wide range of applications from medical diagnostic such as Doppler ultrasound for estimating the blood flow to bringing us joy in the form of music. In this task you will get a better insight in some of acoustic phenomena and ideas about how these phenomena are used in practice.

### Pre-lab exercise

Install the *PhyPhox* application on your phone and record different sounds with the *Audio Spectrum* tool in the *Acoustics* section. Make a recording when it is silent in the room. Think about how you would interpret the graphs you get from the recordings and what information can be obtained from them.

### Equipment list

Two smartphones with *PhyPhox* application installed, computer with spreadsheet software, spring or rubber band

### Experimental skills in focus

Planning an experiment, data collection and analysis, estimating and calculating uncertainty

## Task description

### Interference of sound waves

1. Design an experiment, with all your colleagues as one group, in which you will search for positions in the classroom where local minimums of sound interference occur. Use the *PhyPhox Tone generator* as a sound source.

**Note:** When generating a tone in *PhyPhox* after writing the desired frequency, it is necessary to press OK before broadcasting the sound.

Try to find conditions (source positions, frequency, loudness, ...) in which it is easy to detect minimums. Locate about 10 minimums and take a group photo with students standing on those positions. Discuss conditions and limitations of this experiment.

### Frequency spectrum of different sounds

From the data on the amplitude of sound in time, by applying the Fourier transformation, we can obtain a frequency spectrum that shows us how much individual frequencies are represented in that sound.

2. Using *Audio Spectrum*, record sounds generated by a tuning fork, two musical instruments playing the same note (e.g. C3, C4 (middle C), A4 etc.) and scrunching paper. Each time you make a recording, first take a screenshot of the amplitude in time (*A-t*) graph in the *raw data* section, and then export the *spectrum* data to an Excel sheet. While recording try to eliminate as much external effects as you can.

- a. Describe and compare amplitude in time graphs for every recording. What differences did you find between them?
  - b. Draw a frequency spectrum graph in Excel for each sound you recorded (feel free to eliminate parts of the spectrum that are not relevant for your analysis). For every recorded sound, determine the fundamental frequency and estimate its uncertainty.  
**Note:** The frequency uncertainty is related to the width of a peak by which it is displayed in the frequency spectrum. It can be estimated as half the width of the peak. Often, the peaks are not symmetrical, so to estimate the frequency uncertainty, estimate how far the center of the peak is from both edges of the peak. Take greater from those two distances for frequency uncertainty. To estimate uncertainty from Excel, it is best to use a *scatter plot with smooth lines and markers* to display a graph. When you go to the marked point on the graph with the cursor, the coordinates of that point will be displayed on the screen. Round the uncertainty to one significant figure.
  - c. Determine higher harmonics where it is possible. Analyze and describe the relationship between the fundamental frequency and higher harmonics. What similarities and/or differences did you notice between the sounds of the same note played by different instruments?
3. In *Audio Spectrum raw data* tab, record yourself and then your colleague saying 2 different vowels. What similarities and differences have you noticed?

### The Doppler effect

If the wave source and observer are moving relatively towards or apart from each other, the observer will detect a different wave frequency  $f_d$  from the frequency  $f_s$  that source is emitting. This shift in frequency is known as a Doppler shift and it can be described with the following equation:

$$f_d = f_s \frac{v \pm v_d}{v \mp v_s} \quad (1)$$

Where  $v$  is the speed of wave propagation in medium,  $v_d$  is the velocity of the observer, and  $v_s$  is the velocity of the source. The upper signs (combination of plus and minus) are used when source and observer are approaching each other, and the lower signs when they are moving away from each other.

The Doppler effect is a phenomenon which characterizes waves in general. In this task you will investigate Doppler effect with ultrasound waves.

4. Attach one phone to a vertical spring (or rubber band) so the phone can oscillate at different amplitudes. Place the second phone in the plane of first phone's oscillations. You will use first phone as a moving source emitting sound with constant frequency and the other phone as a frequency detector.

*Note: Think about where the microphone and speaker of each phone are, and what are the best set up conditions to collect and analyze data about detected frequency.*

- a. Sketch how you expect the  $f$ - $t$  graph to look like for the frequencies that the detector phone is detecting while source phone is oscillating.
- b. Emit an 18 or 19 kHz frequency tone from a phone attached to the spring. Measure frequency in time with your detector phone while the source phone is oscillating on the spring. Try to achieve a one-dimensional oscillation as much as it is possible. You can find measurement instructions in the notes below the task. Export collected  $f$ - $t$  data to Excel. Repeat the measurement for 2 more oscillation amplitudes. You don't have to measure amplitudes of the phone oscillations, but note which measurement corresponds to the highest and which corresponds to the lowest amplitude.
  1. **Note:** You can measure frequency in time with *Audio Spectrum*. When you go to the *History chart* there is a *Peak Frequency-time* graph. If you click on it, in the *More tools* section, you can find the *Export this dataset* option and export  $f$ - $t$  data in Excel format.
  2. **Note:** Before you start each measurement, it is necessary to select **8 192** as the number of samples for your measurement in *Settings* section. Our phones are limited in a way that if they collect and analyze a large number of frequencies in a short time the resolution of those frequencies is low. On the other hand, if we choose a high resolution, the phone needs more time to analyze the data so there is a high possibility that some important frequencies will be skipped during the measurement. We choose the middle number of samples as the best ratio of resolution and measuring rate. Consider how long your measurement should take for best results.
- c. Make a frequency-time graph in Excel for each measurement. Feel free to exclude parts of the graph that are not relevant for your analysis. Are the graphs consistent with your predictions?
5. Determine the maximum frequency  $f_{max}$  and minimum frequency  $f_{min}$  for each amplitude. In which position and conditions during the oscillation are these frequencies measured? If all local minimums and maximums on your graph are not the same think about what could be the reason behind this?
6. Derive the expression for the velocity of the phone in the equilibrium position using equation (1) and  $f_{max}$  or  $f_{min}$ .
7. Calculate the velocity (and the associated uncertainty) of the phone in the equilibrium position for three different amplitudes. Take the speed of sound in the air at temperature 20°C to be  $v = 343$  m/s. Are your results in line with your expectations?

**Note:** Calculate the uncertainty of the phone's velocity as a combined standard uncertainty of indirect measurement. The uncertainty of the speed of sound in the air and the emitted frequency are significantly smaller than the uncertainty of the minimum and maximum frequency, so these magnitudes can be considered as constants. Determine the uncertainty of the detected frequency from the resolution of the measuring device, which is 6 Hz.

### Additional task:

Choose one amplitude for which you will determine the velocity of the phone in the equilibrium position when the phone that oscillates detects frequencies, and the stationary phone is the source of the sound. Compare the result with the result obtained when the phone that oscillates is the source of the sound. Discuss your results.

### Assessment

You can write your answers directly into this document.

**Note:** Write down all the results and conclusions that follow those results. Don't forget to attach the graphs that back up your findings. Discuss the limitations of each experiment and describe the difficulties you encountered if there was any.