Sound Waves
Experiment

Physics

Objectives

- Study the sound waves produced by a tuning fork on a resonance box.
- Learn about the period and frequency of sound waves.
- Understand how the length of the tuning fork affects its sound.
- Analyze the spectrum of a sound wave and identify side tones.
- Examine the sound of a musical instrument and explore harmonies.

Modules and Sensors

- PC + NeuLog application
- USB-200 USB module (or BLT-202 Bluetooth module)
- NUL-212 Sound logger sensor

Equipment and Accessories

▪ A-426.6Hz tuning fork
▪ B-480Hz tuning fork
▪ C-512Hz tuning fork
▪ Resonance box (wooden box)
▪ Hammer
▪ String instrument

- Each tuning fork has its musical note and frequency imprinted on its base in Hz.

Introduction

Sound is a mechanical wave created by vibrating particles in a medium. Typically, sound waves are **longitudinal waves**, meaning the particle motion is parallel (and anti-parallel) to the energy transport.

Key properties of sound waves:

- **Frequency (f)**: The number of complete cycles per second, measured in **Hertz (Hz)**.
- **Period (T)**: The time taken for one full cycle, measured in seconds.
- **Wavelength (λ)**: The distance a wave travels in one cycle, measured in meters (m) or millimeters (mm).
- **Velocity (v)**: The speed at which the wave propagates, measured in meters per second (m/s).

$$\frac{1}{T} = f$$

$$\frac{1}{\text{Period}} = \text{Frequency}$$

$$\frac{1}{\text{The time it takes to complete one cycle}} = \text{Number of waves that pass in a period of time}$$

The relationship between these properties is given by:

$$v = f \cdot \lambda$$

$$\text{Velocity} = \text{Frequency} \cdot \text{Wavelength}$$

$$\text{Speed of the waves} = \text{No. of waves that pass in a period of time} \cdot \text{Length of each wave}$$

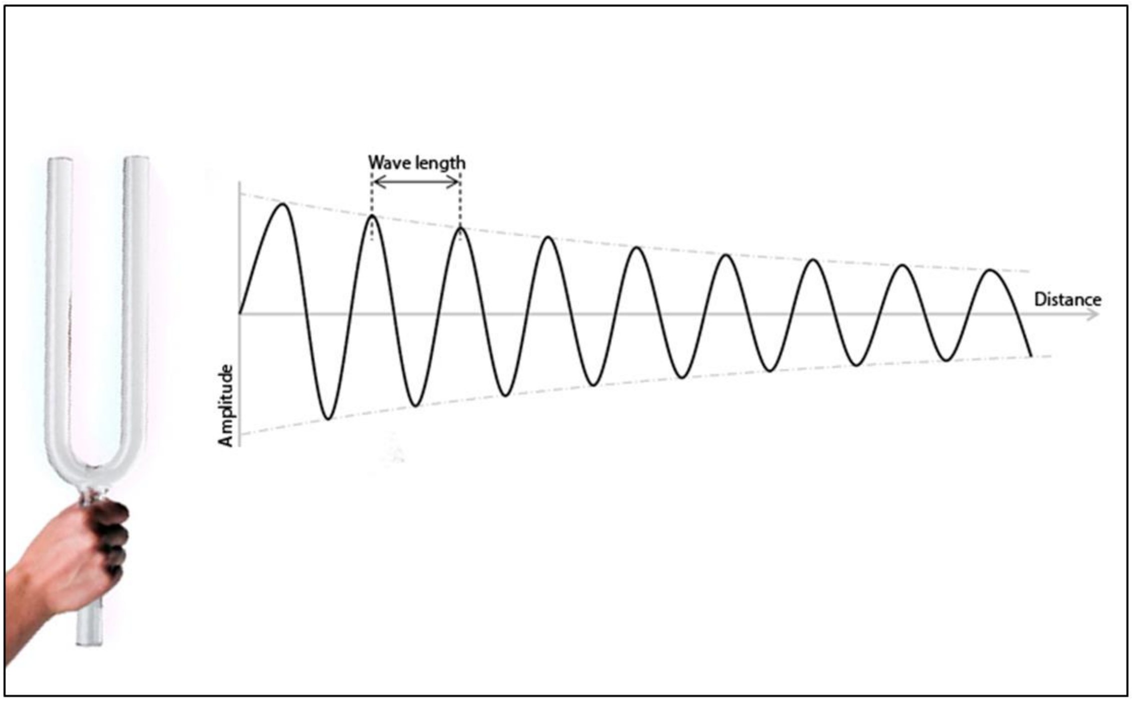
Tuning Forks and Sound Propagation

Tuning forks are widely used by musicians, physicists and sound engineers. They consist of **two rectangular tines** connected to a **stem**, with the tine length determining the frequency.

When struck with a hammer, the tines vibrate, causing air molecules to oscillate:

- **Compression**: Molecules are pushed together (high pressure region).
- **Rarefaction**: Molecules are pulled apart (low pressure region).

A sound sensor (or microphone) detects these oscillations.



The image above illustrates the propagation of sound waves from a vibrating tuning fork. The waves diminish over distance (requiring close measurement) and over time (*necessitating quick data collection*).

A **resonance box** enhances sound intensity by amplifying vibrations at the same frequency as the tuning fork.

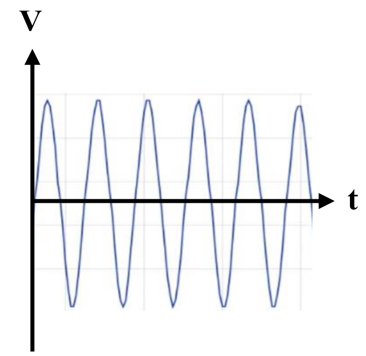
In this activity, we will use a sound logger sensor to measure the period and frequency of sound waves produced by three tuning forks with different lengths.

A sound signal is sine signal according to the following formula:

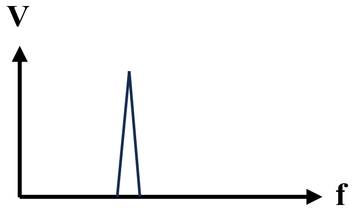
$A(t) = A\sin(2\pi ft)$

- **A** represents the amplitude (maximum value) of the signal
- **f** represents the frequency

The following graph describes a sine wave in the **time domain**:



Another way to describe waves is in the **frequency domain**:



This graph shows the frequency and amplitude of the wave. If the wave is composed of several sine waves, this graph displays them.

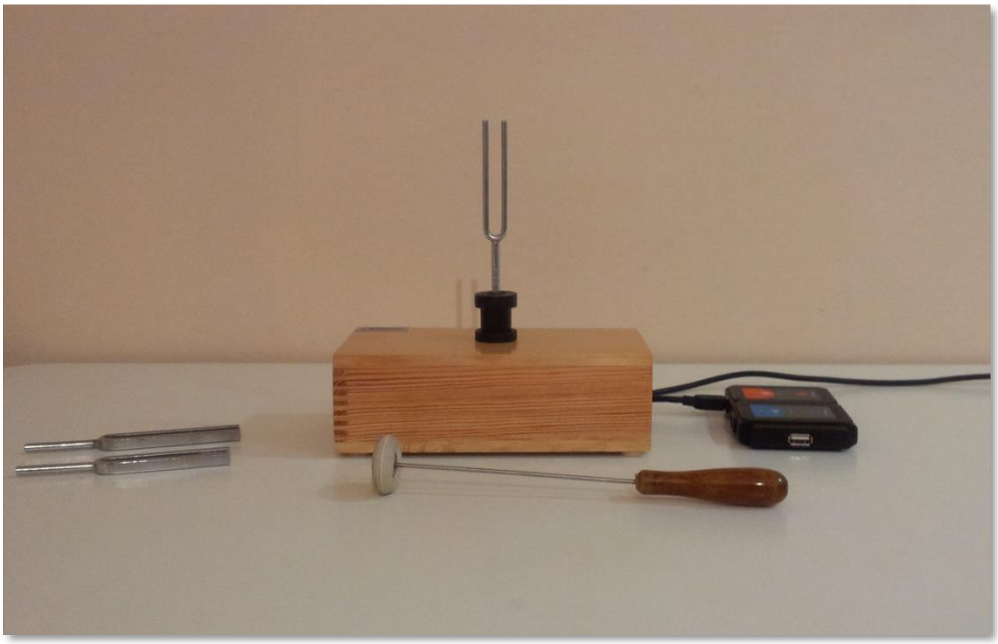
In 1822, the French mathematician **Joseph Fourier** claimed that any function can be expanded into a series of sines. This foundational work was later refined and expanded upon, forming the basis for the various **Fourier transform** methods used today.

The **Fourier transform** is analogous to decomposing a **musical chord** into the intensities of its individual pitches. A **Fourier series** expands a periodic function into a sum of sine and cosine functions.

Procedure

Experiment setup

1. Set up the experiment as shown in the picture below.



2. Insert the C-512Hz tuning fork into the hole of the resonance box.

3. Position the **sound sensor** in front of the resonance box opening.

4. Strike the tuning fork with the hammer to generate sound.

5. Strike the fork and then touch it; observe what happens to the sound.

Sensor setup

6. Connect the USB-200 module to the PC.

7. Ensure the **sound sensor** is connected to the USB-200 module.

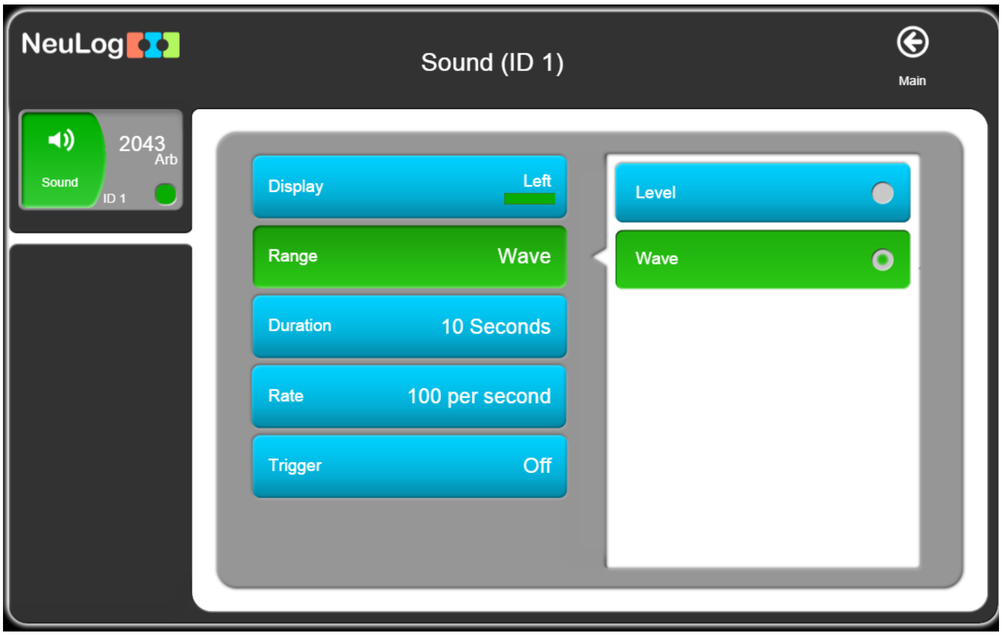
> **Note:**
>
> The following application functions are explained in short. It is recommended to practice the NeuLog application functions (as described in the user manual) beforehand.

8. Open the **NeuLog application** and verify sensor recognition.

Settings

9. Click on the **Sensor's Module** box.

10. Select **Wave mode** button.



11. Click on the  icon to go back to the graph.

12. Click on the **Run experiment** icon  and configure:

Experiment duration to: **25 milliseconds**
Sampling rate to: **10,000 per second**

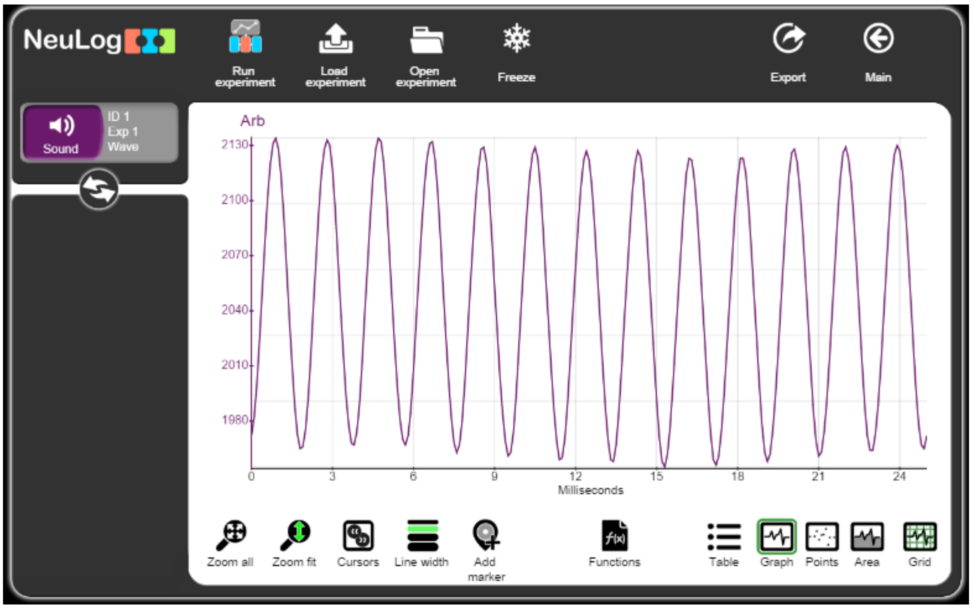
Testing and measurements

13. Strike the tuning fork with the hammer in order to produce sound waves.

14. Immediately, press the **Record** icon .
If possible, one student should strike the fork while another records.

15. Click **Zoom fit**  to visualize the wave.

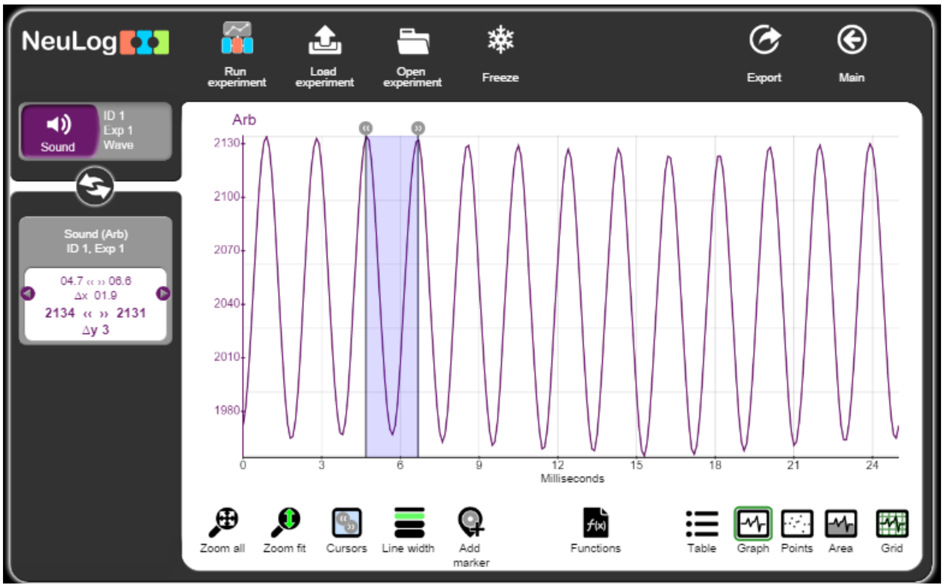
16. Your graph should be similar to the following (If not, repeat the measurement):

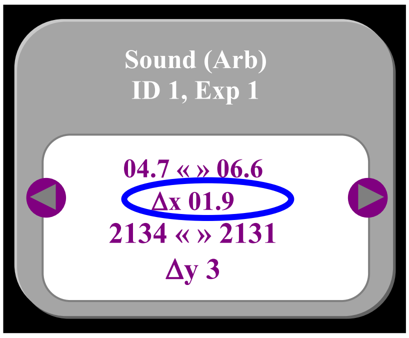


17. Click on the **Export** icon  and then on the **Save value table (.CSV)** button to save your graph.

Calculating the Period and Frequency

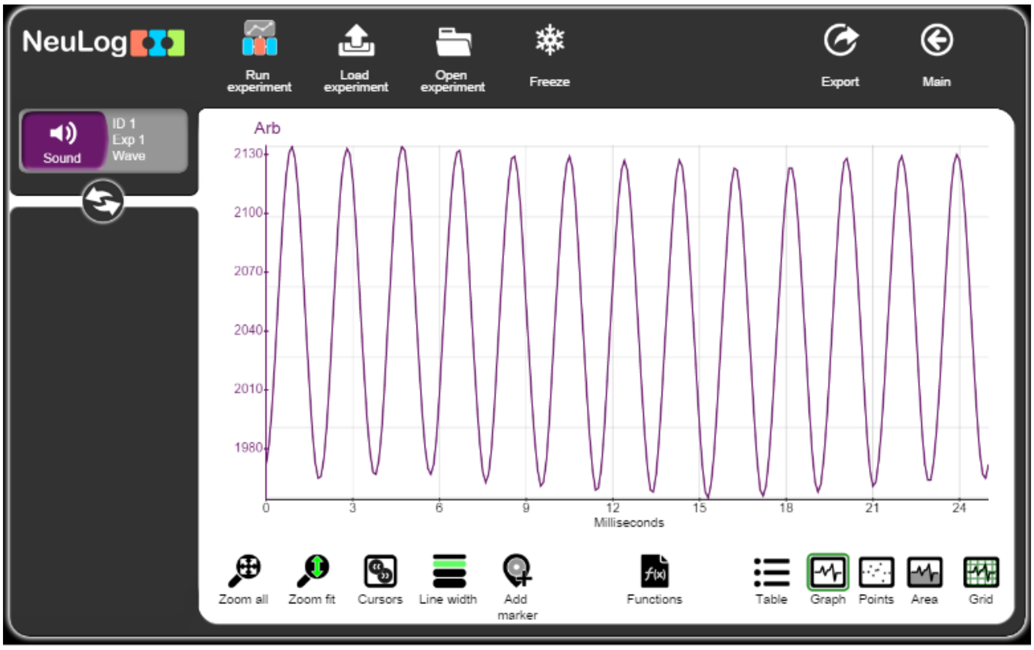
18. Click **Cursors**  and select a full wave cycle.





19. The time for one cycle (T) appears on the left of the screen. is 1.9 milli seconds = 0.0019 s.

20. For more accuracy: divide total measurement time (0.025 s) by the number of complete cycles (~13).



$$T = \frac{0.025\ s}{13} = 0.00192\ s = 1.92ms$$

21. Compute the frequency:

$$F = \frac{1}{0.00192\ s} = 520.8\ s^{-1} = 520.8Hz$$

Or

$$F = \frac{13}{0.025\ s} = 520\ s^{-1} = 520Hz$$

The expected result (512 Hz) should closely match the tuning fork's measurement.

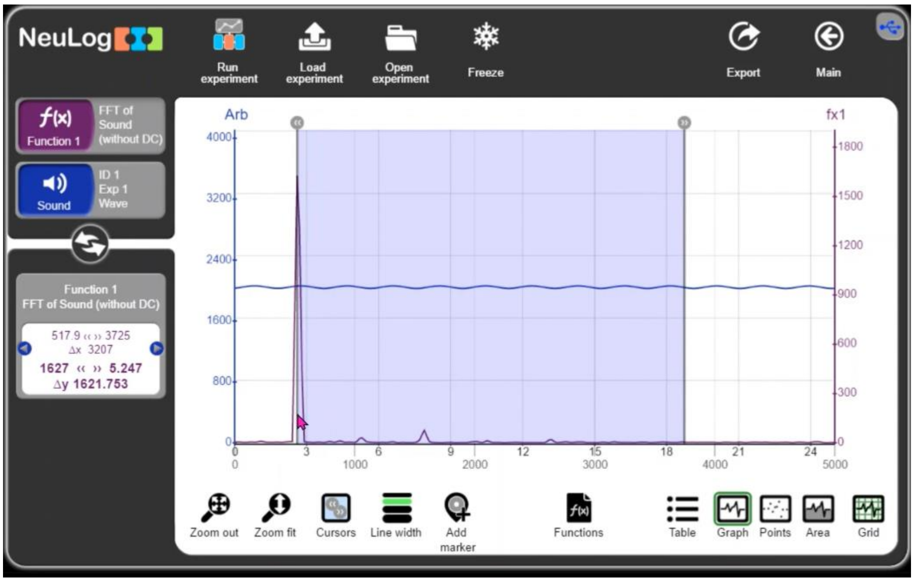
22. Cancel the cursors display.

Fourier transform

23. Click '**FFT of A (without DC)** to generate a frequency graph.

24. Move the left cursor to the **peak**.

25. Adjust the display on the left, to show function frequencies.



The frequency displayed on the left is 517.9 Hz

String musical instrument

26. Clear the FFT graph by pressing '**Clear all functions**' under '**Functions**' options.

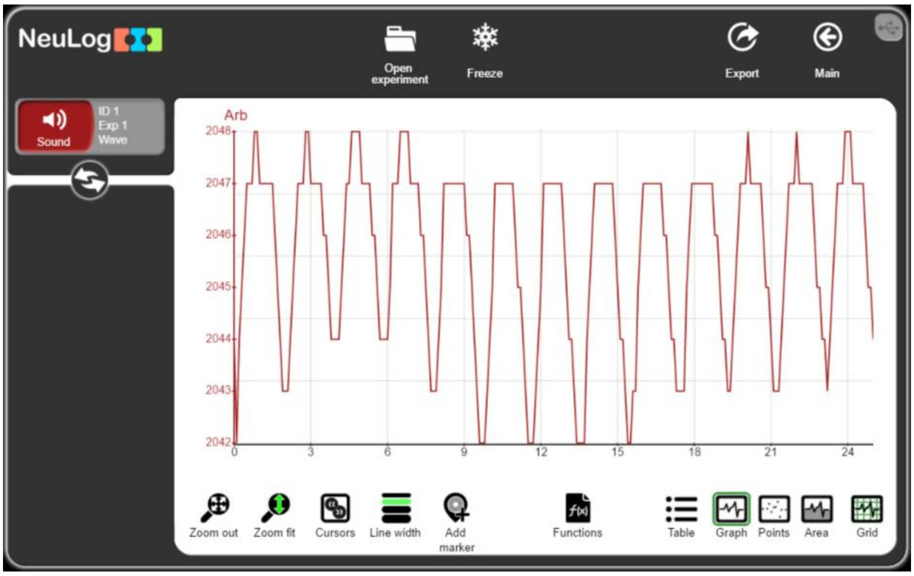
27. Let's check the sound waves of a musical instrument
The first string of this ukulele is tuned to C note (512 Hz)

28. Return to the main screen and click on the '**Run experiment**' button,

29. Set the experiment duration to 25 milli-seconds.
Set the sampling rate to 10,000 samples per second

30. Bring the ukulele close to the sound sensor
Play the C string and immediately, press the 'Record' button

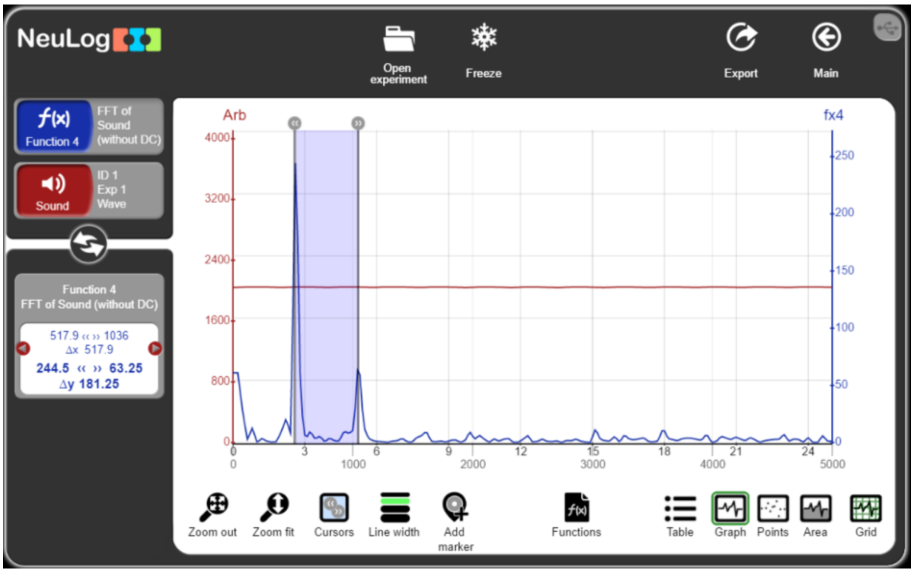
31. Click on '**Zoom fit**'



The waves are not sinusoidal.
The sound box of the ukulele amplifies the string sound by adding echoes and creates over tones.
The quality of the sound box affects the quality and the beauty of the musical instrument sound

32. Click '**FFT of A (without DC)** and create a function 1 graph
There are two peaks here.
Move the left cursor to the peak on the left
Move the right cursor to the peak on the right

33. Change the display on the left to show the frequencies of function 1 graph



The frequency displayed of the left peak is 517.9 Hz
The frequency displayed of the right peak is 1036 Hz
The over tone wave which its frequence is multiple of the base frequence is called harmony
We can find more than one harmony

Challenge research

34. Repeat the tuning fork experiment using the A-426.6Hz tuning fork and then the B-480Hz tuning fork.

    Longer tines vibrate more slowly; therefore, they produce lower frequencies and longer wavelengths.

35. Repeat the last experiment with high and low quality of musical instruments

Summary questions

1. Calculate the tuning fork sound waves period and frequency as demonstrated above (for all the measurements). Compare the calculated frequencies to the ones imprinted on the tuning forks.

2. What happened when you touched the tuning fork after hitting it? Explain.

3. Did you hear a difference in the sound produced by each tuning fork? What is the connection between frequency and pitch?

4. Can you see the difference between high and low quality of musical instruments in their FFT analysis?