Case File 3

Name That Tune: Matching musical tones through waveform analysis

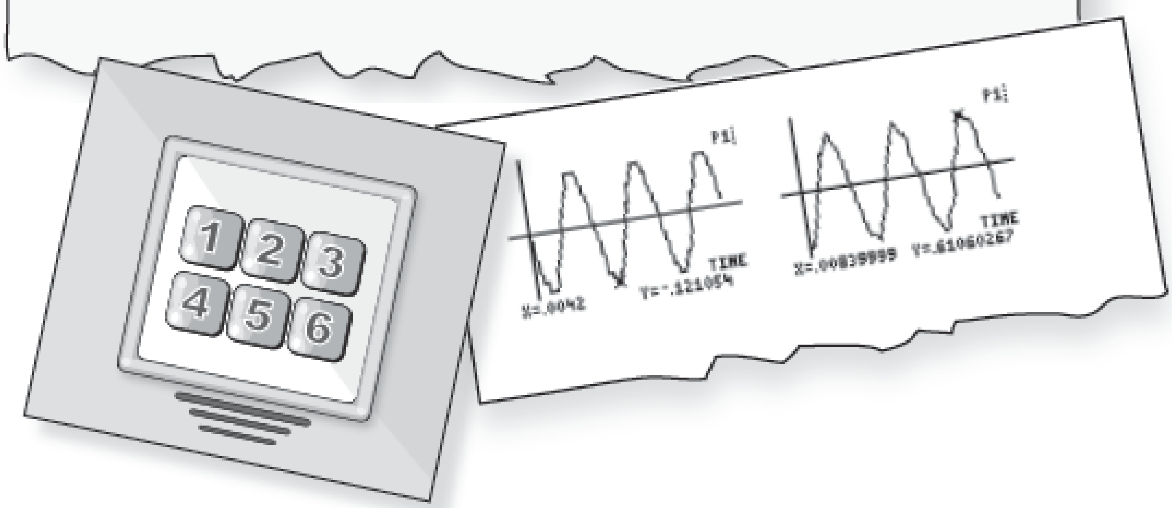
Identify musical notes based on their frequencies.

Capt. Ramirez:

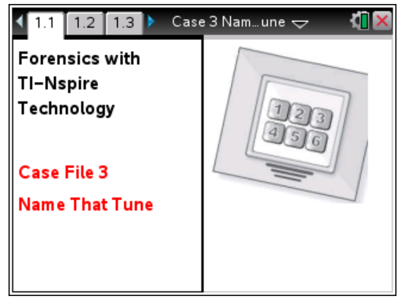
On Tuesday night, wealthy recluse Tajia Winslow was robbed of her famous collection of rubies, known around the world as the Winslow Ten. The rubies were stored in a safe behind a painting in Ms. Winslow's basement. The safe has a computer lock similar to a telephone keypad. Each time a number on the pad is pushed, a specific tone sounds. This method was developed to assist Ms. Winslow in opening the safe, because she is elderly and has difficulty reading the numbers on the keypad. She thought she was the only person who knew the tune of the combination.

At this time, our main suspect in the case is Ms. Winslow's maintenance technician, 28-year-old Thomas Evans. Our investigators found high-tech computer and sound-recording equipment in Mr. Evans's apartment. Upon searching his hard drive, we discovered files containing digitized waveforms of a musical sequence.

We think Mr. Evans recorded the sounds made by the safe's keypad and used them to determine the combination of the lock. The computer files, along with the safe keypad, have been sent to the lab for analysis and comparison.



About the Lesson



- In this activity, students analyze sound waves to calculate the frequency, or pitch, of musical notes.
- Teaching time: one 45 minute class period

Science Objectives

- Identify the musical notes that make up the combination to a safe.
- Detect the waveform of a musical note, using a Microphone.
- Calculate the frequency of a musical note from the period of its waveform.

Activity Materials

- TI-Nspire™ Technology
- *Case_3_Name_That_Tune.tns* file
- TI-Nspire Lab Cradle
- Vernier microphone
- electronic keyboard or tuning forks and a soft tuning-fork hammer

TI-Nspire™ Navigator™

- Send out *Case_3_Name_That_Tune.tns* file.
- Monitor student progress using Class Capture.
- Use Live Presenter to spotlight student answers.

Teacher Notes and Teaching Tips

- The student activity sheet and .tns file contain the complete instructions for data collection. All assessment questions are also included in both places giving you the flexibility to either collect the .tns files with student data/answers using TI-Nspire Navigator or to collect the handwritten version of the answers.
- In this lab, students must have a Data Cradle to connect the microphone. Data collection is too rapid for the EasyLink interface.
- Before assigning the activity, you may want to review the basics of sound waves and the relationships between wavelength, period, frequency, and speed. Make sure students understand the relationship between pitch and frequency.
- Divide the class into groups of at least three students per group. It is easiest to perform the experiment if one person operates the keyboard, one person holds the Microphone, and the other person operates the TI-Nspire handheld or software.
- Students can use electronic keyboards that are able to play a flute sound OR tuning forks.

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Allow students to read the forensics scenario on the first page of their student activity sheet.

Background Information

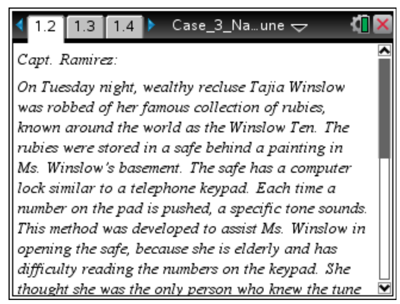
All waves have three characteristic properties: wavelength, λ; frequency, f; and speed, v. The relationship between these properties is shown by the equation $v = f \cdot \lambda$. This equation can easily be obtained through unit analysis: wavelength has units of distance, frequency has units of inverse time (e.g., s-1 or Hz), and speed has units of distance per unit time. The wavelength of a wave is the distance between two successive peaks (crests) or valleys (troughs). The frequency is a measure of how many crests or troughs pass a given point in a certain period of time (usually 1 second). Depending on the type of wave in question, wavelength and frequency can cause noticeable changes in the observable properties of the wave. For example, different wavelengths of visible light appear to have different colors, and different frequencies of sound waves have different pitches.

Procedure

Part 1 – Preparing for Data Collection

Move to pages 1.2–1.5.

1. Students read the directions on these pages to become familiar with how the data will be collected.



Move to page 2.1.

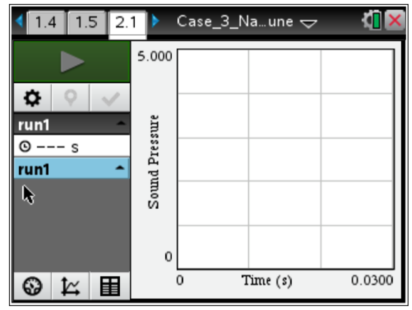
2. Students are to set up the keyboard and microphone. You may want to label the notes on the keyboard.

   The table at the right shows the notes and their corresponding frequencies.

   Make sure the keyboards to play a flute, which is a pure tone.

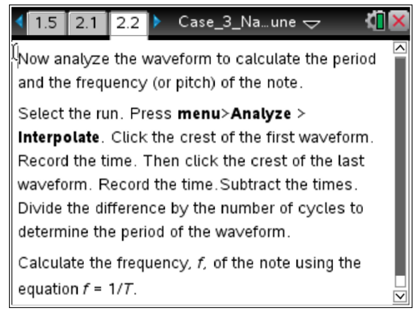
Note	Frequency(Hz)
C_4	263
D_4	295
E_4	330
A_4	443
B_4	497
C_5	526

Part 2 – Collecting Data



3. Students will use the microphone to collect the data for all six notes. At the end of the data collection, students should have six “runs” of data.

Part 3 – Analyzing the Data



4. Once students have collected suitable data, they can analyze the waveform to calculate the period and the frequency (or pitch) of the note.

   If needed, students can insert a *Lists & Spreadsheet* application to record the time of the crests and calculate the period and frequency.

5. Students analyze all six notes and complete the table in the Evidence Record.

Evidence Record

Sample results:

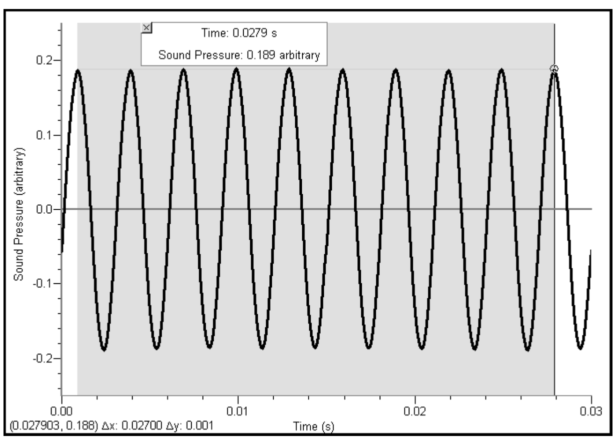
Note	Period, *T* (sec)	Frequency, *f* (cycles/sec or Hz)
C_4	0.0038	263
D_4	0.0034	295
E_4	0.003	333
A_4	0.0023	435
B_4	0.002	497
C_5	0.0019	526

6. Students are to the period and frequency of each of the notes in the **Sample Evidence**.
7. Then students compare the frequencies of the notes recorded in the **Evidence Record** to the frequencies of the notes in the **Sample Evidence** (the notes found on Evans's computer hard drive).

Sample Data

Notes from Mr. Evans's Computer Hard Drive

First note

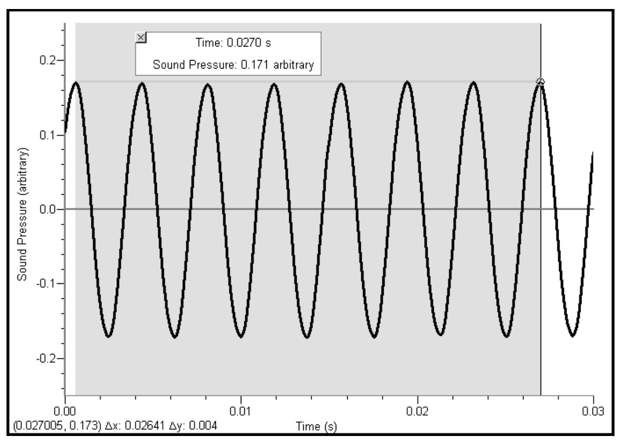


Period: 0.003

Frequency: 333

Note: E_4 (330 Hz)

Second note



Period: 0.00377

Frequency: 265

Note: C_4 (263 Hz)

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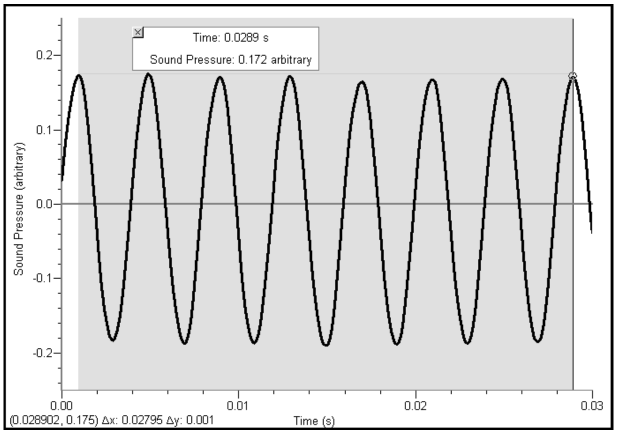
Third note

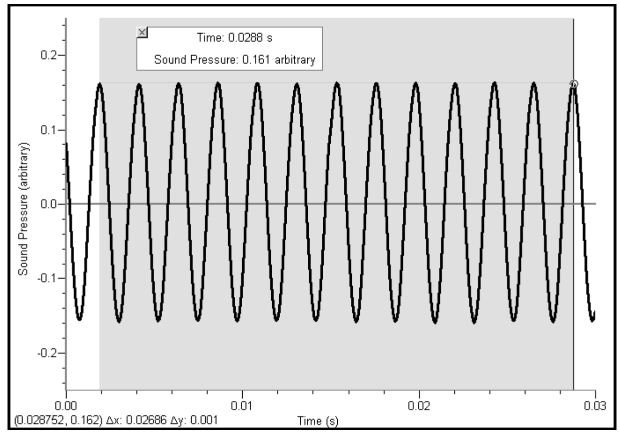


Period: 0.00202

Frequency: 494

Note: B_4 (497 Hz)

Fourth note

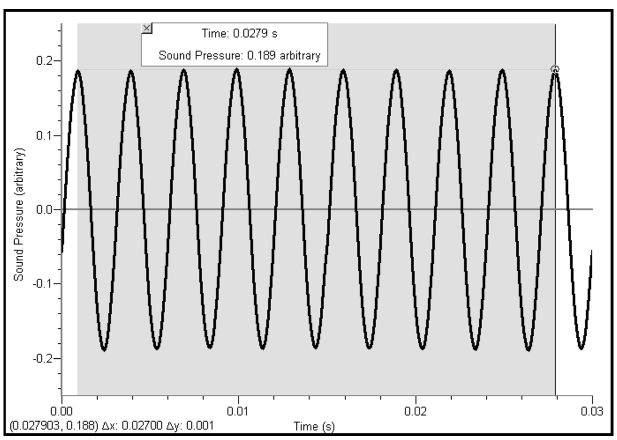


Period: 0.00223

Frequency: 446

Note: A_4 (443 Hz)

Fifth note

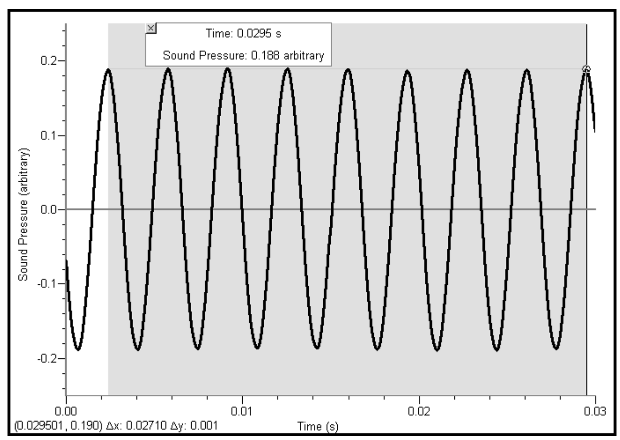


Period: 0.00201

Frequency: 496

Note: B_4 (496 Hz)

Sixth note



Period: 0.00339

Frequency: 295

Note: D_4 (295 Hz)

Order of tones in Evans's hard drive, using the musical notes: B, E, B, A, D, C

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Case Analysis

Move to pages 3.1 – 3.7.

Have students answer the following questions in the .tns file, on their activity sheet, or both.

Q1. In Step 4, you measured the time between two crests in the waveform of each note. Could you have determined the frequency from two adjacent troughs (low points) in the waveforms? Explain why the period and frequency of a waveform calculated using the time between two crests are the same as when using two troughs.

Answer: Because waves are symmetrical, the distance between two adjacent troughs is the same as the distance between two adjacent crests.

Q2. Like all waves, sound waves have a frequency and a wavelength. The speed of sound in air is about 340 m/s. Frequency is measured in cycles per second. Speed is measured in meters per second. Wavelength is measured in meters. Using this information, write an equation that shows how you can calculate the wavelength of a wave if you know its frequency and speed.

Answer: wavelength (m) = speed (m/s) ÷ frequency (cycles per second)

Q3. Using the equation you wrote for Question 2, calculate the wavelength of each of the notes produced by the tuning forks in your Evidence Record. Show all your work.

Answer: C_4: 340 m/s ÷ 263/s = 1.29 m
D_4: 340 m/s ÷ 295/s = 1.15 m
E_4: 340 m/s ÷ 333/s = 1.02 m
A_4: 340 m/s ÷ 435/s = 0.78 m
B_4: 340 m/s ÷ 597/s = 0.68 m
C_4: 340 m/s ÷ 526/s = 0.65 m

Q4. Using the equation you wrote for Question 2, explain how frequency and wavelength are related.

Answer: As frequency increases, wavelength decreases. They are inversely related.

Q5. The police determined that the correct combination for the safe corresponded to the following order of wavelengths: E_4, C_5, B_4, A_4, C_4, D_4.
Did Evans record the safe combination, or was his recording of another combination of notes? How do you know?

Answer: Evans did not record the safe combination. The recording on his hard drive was of another combination of notes.

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