**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.
Name That Tune

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.

MATERIALS

- computer
- Vernier computer interface
- electronic keyboard
- Logger Pro
- Vernier Microphone
- soft tuning-fork hammer

PROCEDURE

1. Connect the Microphone to channel 1 of the interface.

2. Prepare the computer for data collection by opening the file “03 Name That Tune” from the Forensics with Vernier folder of Logger Pro.

3. Collect data to determine the frequency of each note. The easiest way to do this is to split up the group so that one person operates the keyboard, a second person holds the Microphone, and a third operates the computer.
   a. Set the keyboard to play a flute tone.
   b. Produce the first note to study, C. Hold the tone steady for a second or two (until the waveform appears on the screen).
   c. Hold the Microphone about 1 cm from the keyboard speaker and click to begin data collection.

   ![Figure 1](image)

4. The waveform on the screen should look like one of the waveforms in the Sample Evidence section of this handout. If it does not, reposition the microphone and repeat data collection.

5. Once you have collected suitable data, you are ready to analyze the waveform to calculate the period and the frequency (or pitch) of the note.
   a. Click the Examine button, and use the mouse to trace across the graph. Position the
mouse cursor at the crest of the first waveform. Click and hold down the left mouse button and then drag the cursor to the crest of the last waveform. In the bottom left corner of the displayed graph you will find the difference in time, $\Delta t$ value, between the crest of the first waveform and the crest of the last waveform. Divide the difference, $\Delta t$, by the number of cycles to determine the period of the waveform. Record the period, to three significant figures, in your Evidence Record. For example, 0.00230 has three significant figures.

b. Calculate the frequency, $f$, of the note using the equation $f = 1/T$. Record the frequency of the note in the Evidence Record. The unit for frequency is s$^{-1}$ or hertz (Hz). One hertz equals one cycle per second.

6. Repeat Steps 3–5 for the remaining notes. Use Figure 2 as a reference point to locate the notes. The musical notes are also identified with a subscript number indicating what octave they are in, such as C$_4$.

7. Calculate the period and frequency of each of the notes in the Sample Evidence section of this handout, using the $\Delta t$ values shown for each set of waveforms.

8. Compare the frequencies of the notes recorded in the Evidence Record to the frequencies of the notes found on Evans’s computer hard drive. Determine the combination of notes that was stored on the hard drive, and record it in the Evidence Record.
SAMPLE EVIDENCE
Notes from Mr. Evans’s Computer Hard Drive

First note

Period: ____________
Frequency: ___________
Note: ____________

Second note

Period: ____________
Frequency: ___________
Note: ____________
Case 3

Third note

Period: ____________
Frequency: ____________
Note: ____________

Fourth note

Period: ____________
Frequency: ____________
Note: ____________
Fifth note

Period: __________
Frequency: __________
Note: __________

Sixth note

Period: __________
Frequency: __________
Note: __________
EVIDENCE RECORD

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<thead>
<tr>
<th>Note</th>
<th>Period, T (s)</th>
<th>Frequency, f (cycles/s or Hz)</th>
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Order of tones in Evans’s hard drive, using the musical notes: __________________________

CASE ANALYSIS

1. In Step 5, you measured the time between two crests in the waveform of each tuning fork. 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.

2. 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.

3. 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.

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

5. The police determined that the correct combination for the safe corresponded to the following order of wavelengths: E₄, C₅, B₄, A₄, C₄, D₄.

   Did Evans record the safe combination, or was his recording of another combination of notes? How do you know?
Vernier Lab Safety Instructions Disclaimer

THIS IS AN EVALUATION COPY OF THE VERNIER STUDENT LAB.

This copy does not include:

- Safety information
- Essential instructor background information
- Directions for preparing solutions
- Important tips for successfully doing these labs

The complete Forensics with Vernier lab manual includes 14 labs and essential teacher information. The full lab book is available for purchase at:  
http://www.vernier.com/cmat/fwv.html