Case File 3

Name That Tune: Matching musical tones through waveform analysis

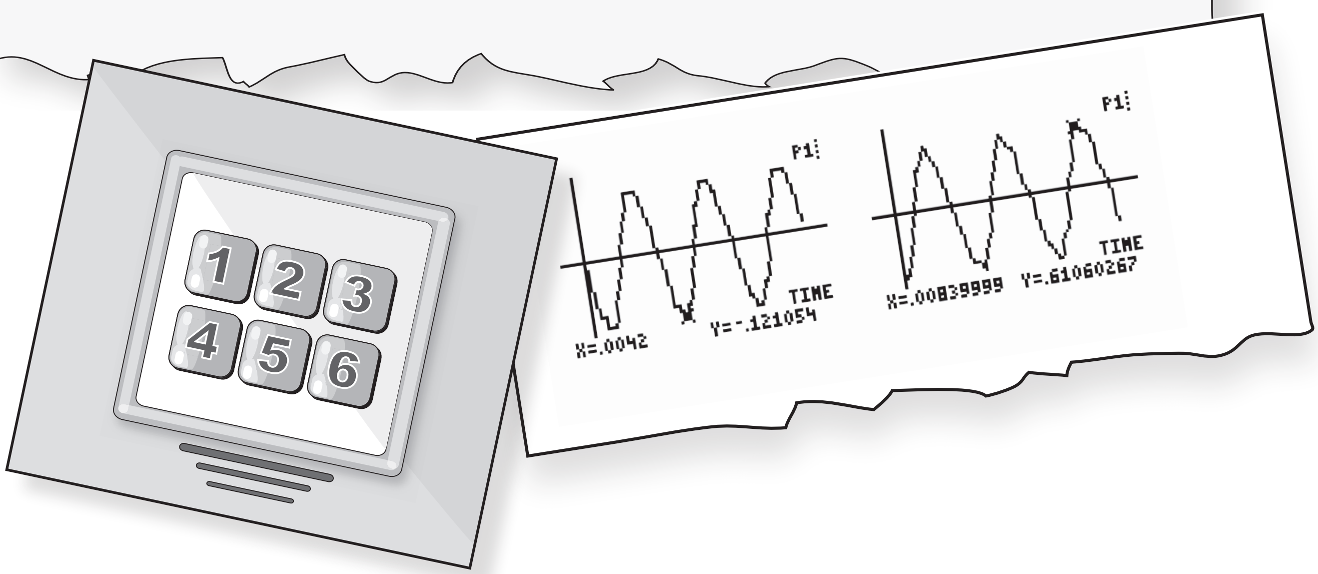
Identify musical notes based on their frequencies.

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.



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Forensics Objective

- identify the musical notes that make up the combination to a safe

Science and Mathematics Objectives

- detect the waveform of a musical note, using a Microphone
- calculate the frequency of a musical note from the period of its waveform

Materials (for each group)

- calculator from TI-83/TI-84 Plus™ Family
- Calculator-Based Laboratory ™ 2 (CBL™ 2) and link cable
- Vernier EasyData™ application
- Vernier Microphone
- 6 tuning forks of different frequencies
- soft tuning-fork hammer

Procedure

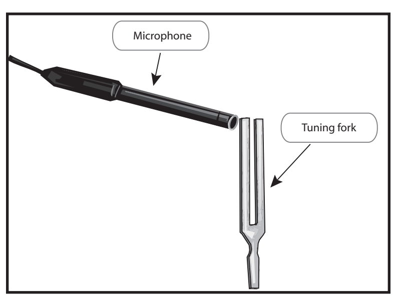
1. Connect the CBL 2 to your calculator with the link cable.

2. Plug the Microphone probe into channel 1 (~CH1) of the CBL 2.

3. Load the EasyData application and set up to use the Microphone probe.
   a) Press APPS.
   b) Use ▼ to highlight :EasyData. Press ENTER to start the application. The EasyData application will start automatically.

TIP! At the bottom of the Main screen are five options (File, Setup, Start, Graph, and Quit). Each of these options can be selected by pressing the calculator key located below it (Y=, WINDOW, ZOOM, TRACE, or GRAPH).

4. Collect data to determine the frequency of each tuning fork. The easiest way to do this is to split up the group so that one person holds the tuning fork, a second person holds the Microphone, and a third controls the calculator.
   a) In the Evidence Record, write the number of the label found on the first tuning fork.
   b) Strike the tuning fork with the soft hammer and then hold the fork straight up and down.
   c) Hold the Microphone about 1 cm from the space between the prongs, as shown in the diagram below.



(Note: *Never* strike the tuning fork on a hard surface; it may change the waveform of the tuning fork.)

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d) Select **Start** to start data collection. If you get a message about overwriting data, select **OK**. The waveform will appear on your screen within a few seconds. It should look like one of the waveforms on the Waveforms of the Notes Taken from Evans's Computer Hard Drive handout. If it does not, repeat the analysis by selecting **Main** and repeating steps 4b–4c. Change the location of the vibrating tongs of the tuning fork until you get a clear waveform image. You will probably have to practice several times.

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) Press and hold ▶ to move the cursor to a crest (highest point) of the waveform.
   b) At the bottom of the display, you will see **X=** and **Y=**. The **X=** is the time (in seconds). The **Y=** is the amplitude of the sound wave. Record the time, **X=**, displayed at the crest of the waveform as t_1 in the Evidence Record. Then move the cursor to the next crest, and record this time as t_2 in the Evidence Record. The value $t_2 - t_1$ is the period, T, of the note. Record the value you calculate for T in the Evidence Record.
   c) Calculate the frequency, f, of the note using the equation $f = \frac{1}{T}$. Record the frequency of the tuning fork in the Evidence Record. The unit for frequency is s^{-1} or hertz (Hz). One hertz equals one cycle per second.
   d) When you have finished analyzing the waveform, press **ENTER**. Press **2** to repeat the analysis with another tuning fork.

6. Repeat steps 4 and 5 with the remaining tuning forks.

7. Calculate the period and frequency of each of the notes on the Waveforms of the Notes Taken from Evans's Computer Hard Drive handout, using the **X=** values shown as t_1 and t_2 for each pair of waveforms.

8. Compare the frequencies in the Evidence Record to the frequencies 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.

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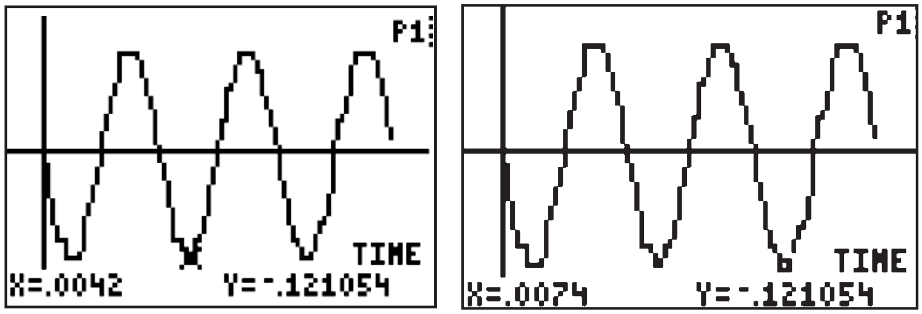
Waveforms of the Notes Taken from Evans's Computer Hard Drive

First note

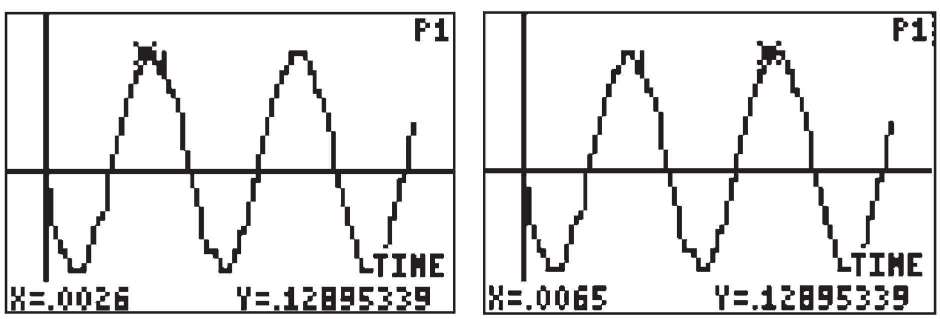


Period: ____________

Frequency: ___________

Note: ____________

Second note



Period: ____________

Frequency: ___________

Note: ____________

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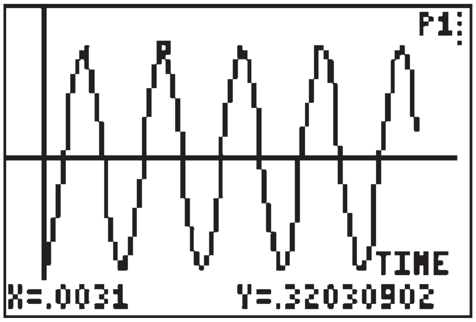
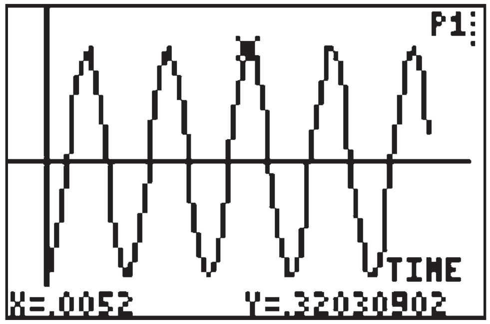
Third note



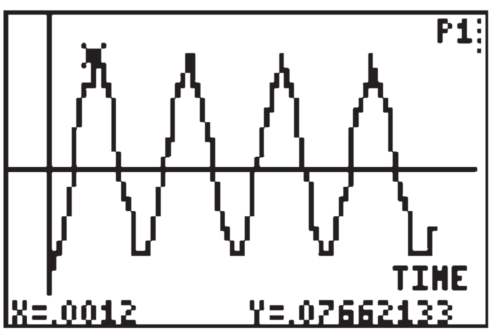


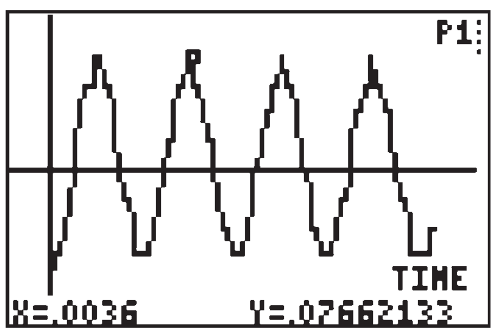
Period: ____________

Frequency: ___________

Note: ____________

Fourth note





Period: ____________

Frequency: ___________

Note: ____________

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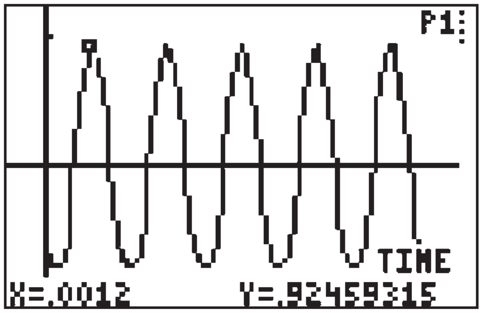
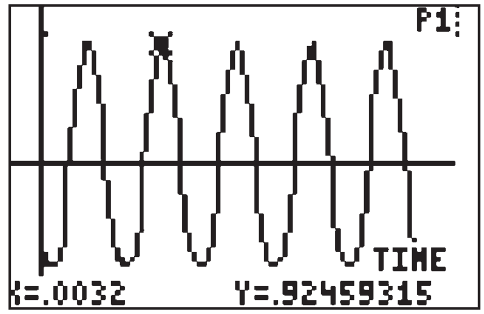
Fifth note



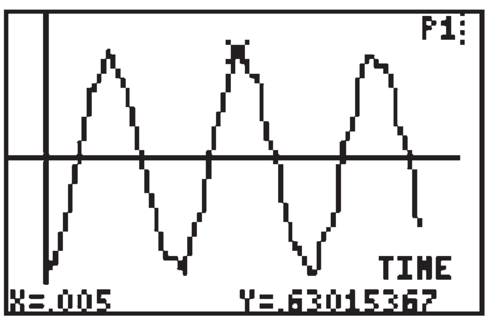


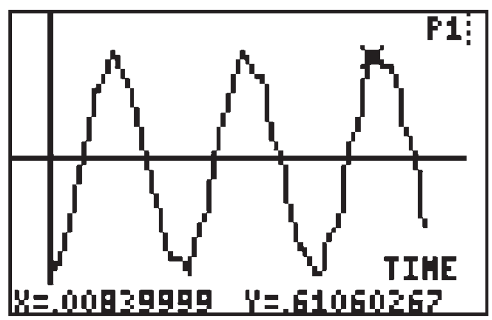
Period: ____________

Frequency: ___________

Note: ____________

Sixth note





Period: ____________

Frequency: ___________

Note: ____________

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NAME: ______________________________________

DATE: ______________________________________

Evidence Record

Tuning Fork Number	Time at First Crest, t_1(s)	Time at Second Crest, t_2(s)	Period, T (s)	Frequency, f (cycles/s or Hz)

Order of tones in Evans's hard drive, using numbers on tuning forks: ____________________

Case Analysis

1. In step 5, you measured the time between two adjacent crests in the waveform of each tuning fork. However, some of the times that you calculated on the handout of Evans's hard drive were determined 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 same equation, 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 : _________________________.
   Did Evans record the safe combination, or was his recording of another combination of notes? How do you know?

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Case File 3
Name That Tune: Matching musical tones through waveform analysis

Teacher Notes

Teaching time: one class period

In this activity, students analyze sound waves to calculate the frequency, or pitch, of musical notes.

Tips

- Note that EasyLink does not support the Microphone. To use the Microphone, you must have a CBL (Calculator-Based Laboratory).
- 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.
- Explain to the students that the calculated frequencies for the same tuning fork may vary by as much as 12 Hz. This is because the calculator rounds off the time between data points, introducing error into the measurements. For example, a period of 0.00195 s (frequency 513 Hz) would be recorded as 0.002 s by the calculator, giving a frequency of 500 Hz.
- Divide the class into groups of at least three students per group. It is easiest to perform the experiment if one person holds the tuning fork, one holds the Microphone, and one presses the keys on the calculator.
- Sometimes the fork works best when the base is sitting on a table and the hum is audible.
- The calculator also has a frequency function. Students may be tempted to use this function directly, rather than analyze the waveforms. However, without practice, it is difficult to get the right frequency using this function. The frequencies given are often multiples of the actual frequencies. If a student's data seem way off, this is probably the problem.
- Note that even when the fork appears to have become silent, it is still vibrating. You may or may not want to warn students that touching a vibrating tuning fork to teeth can break the teeth.

Lab Preparation

- Use a stick-on label to cover the identity and frequency of the note produced by each tuning fork, and assign each fork a number.
- You can use the following table to number the tuning forks. Provision has been made in the table for you to give different groups tuning forks that have different number schemes.

Note	Frequency (Hz)	Number for Group A	Number for Group B	Number for Group C	Number for Group D	Number for Group E	Number for Group F	Number for Group G
C	256	1	2	6	5	4	3	1
D	288	2	4	5	3	6	1	6
E	320	3	6	4	2	5	6	2
A	426.7	4	1	3	1	2	4	5
B	480	5	3	2	4	3	5	3
C	512	6	5	1	6	1	2	4

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- The following table gives the safe combination for each group.

Group	Combination
A	3, 1, 5, 4, 6, 2
B	6, 2, 3, 1, 5, 4
C	4, 6, 2, 3, 1, 5
D	2, 5, 4, 1, 6, 3
E	5, 4, 3, 2, 1, 6
F	6, 3, 5, 4, 2, 1
G	2, 1, 3, 5, 4, 6

- You will need to tell the students the correct combination so that they can answer question 5 in the Case Analysis.

Background Information

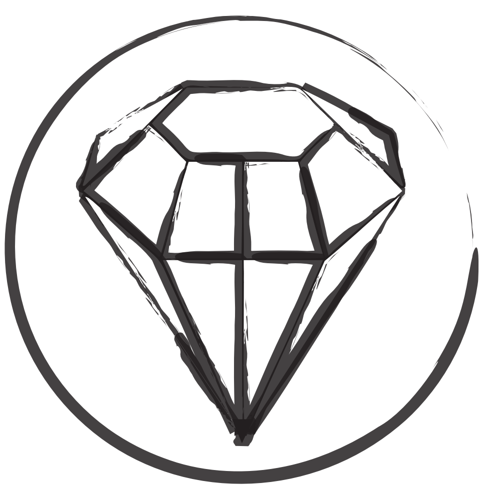
All waves have three characteristic properties: wavelength, λ; frequency, f; and speed, v. These properties are related by the equation $v = f\lambda$. This equation can easily be obtained through unit analysis: wavelength has units of distance, frequency has units of inverse time (e.g., s^{-1} or Hz), 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 peaks 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.

Resources

Tuning forks can be ordered from a science supply catalog or borrowed from the music department at your school.

Modifications

As an extension, or if tuning forks are not available, you may be able to use the notes produced by a touch-tone telephone. You may need to develop a new handout to accommodate the phone notes.



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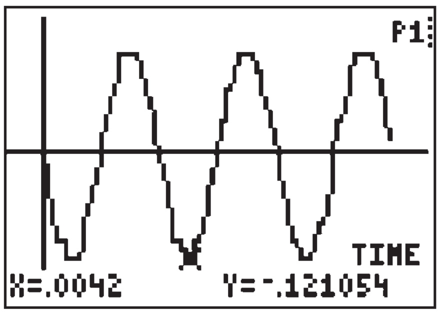
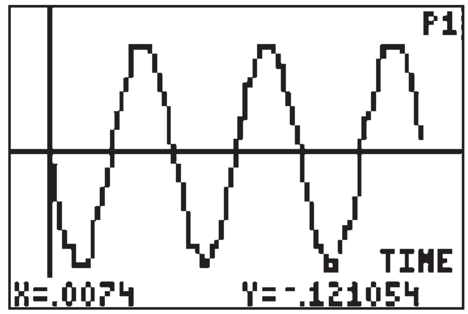
Sample Data

Waveforms of the Notes Taken from Evans's Computer Hard Drive

First note



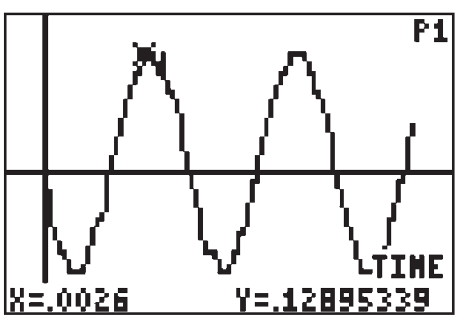


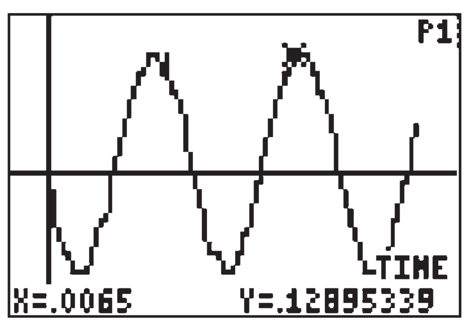
Period: 0.0032 s

Frequency: 312 Hz

Note: E (320 Hz)

Second note





Period: 0.0039 s

Frequency: 256 Hz

Note: C (256 Hz)

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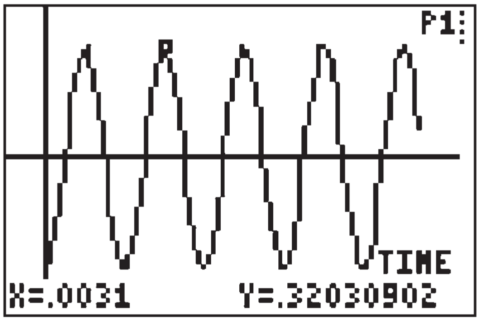
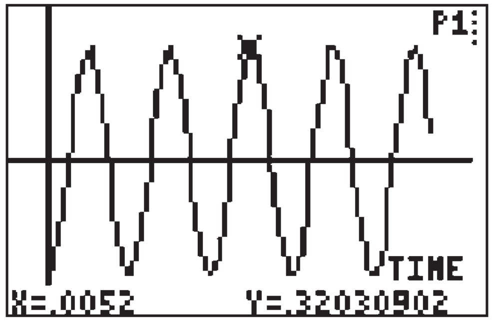
Third note



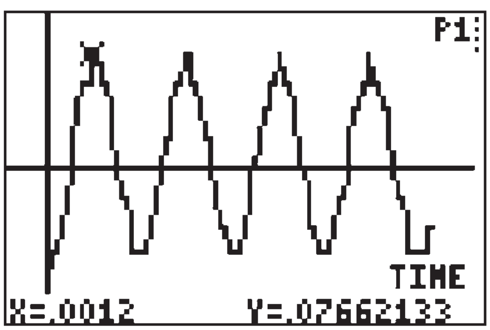


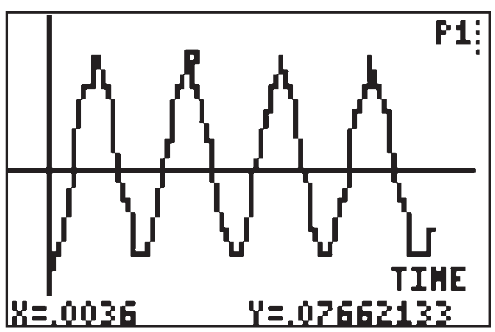
Period: 0.0021 s

Frequency: 476 Hz

Note: B (480 Hz)

Fourth note





Period: 0.0024 s

Frequency: 417 Hz

Note: A (426.7 Hz)

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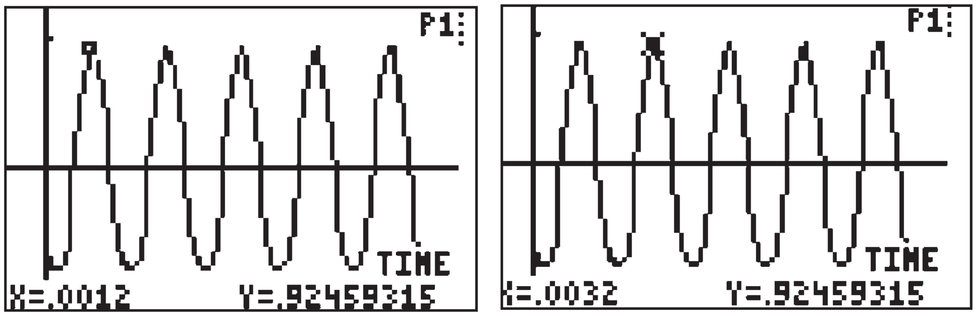
Fifth note

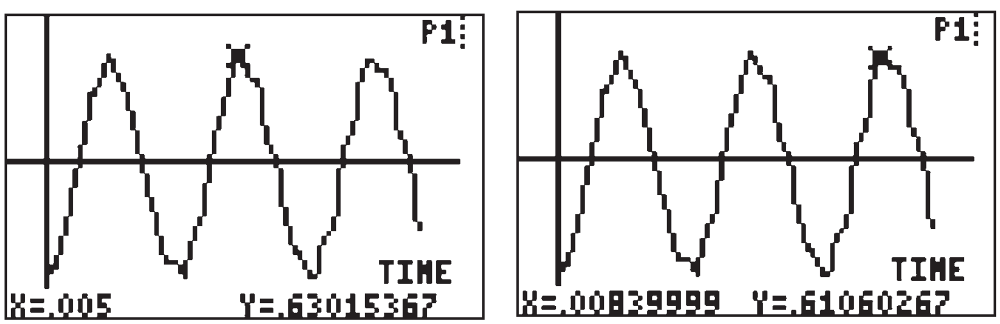


Period: 0.0020 s

Frequency: 500 Hz

Note: C (512 Hz)

Sixth note



Period: 0.0034 s

Frequency: 294 Hz

Note: D (288 Hz)

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The results in the following table use the tuning fork numbers for group A.

Tuning Fork Number	Time at First Crest, t_1(s)	Time at Second Crest, t_2(s)	Period, T (s)	Frequency, f (cycles/s or Hz)
1	0.003	0.0069	0.0039	256
2	0.0033	0.0066	0.0033	303
3	0.0025	0.0057	0.0032	313
4	0.0015	0.0038	0.0023	435
5	0.0016	0.0037	0.0021	476
6	0.0015	0.0035	0.0020	500

Order of tones in Evans's hard drive, using numbers on tuning forks:
3, 1, 5, 4, 6, 2

Case Analysis Answers

1. In step 5, you measured the time between two adjacent crests in the waveform of each tuning fork. However, some of the times that you calculated on the handout of Evans's hard drive were determined 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.
   Because waves are symmetrical, the distance between two adjacent troughs is the same as the distance between two adjacent crests.
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.
   wavelength (m) = speed (m/s) ÷ frequency (cycles per second)
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.
   C (256 Hz) : 340 m/s ÷ 256/s = 1.3 m
   B (480 Hz) : 340 m/s ÷ 480/s = 0.71 m
   A (426.7 Hz): 340 m/s ÷ 426.7/s = 0.80 m
   E (320 Hz): 340 m/s ÷ 320/s = 1.1 m
   D (288 Hz): 340 m/s ÷ 288/s = 1.2 m
   C (512 Hz) : 340 m/s ÷ 512/s = 0.66 m
4. Using the same equation, explain how frequency and wavelength are related.
   As frequency increases, wavelength decreases (they are inversely related).
5. The police determined that the correct combination for the safe corresponded to the following order of wavelengths : ____________________________.
   Did Evans record the safe combination, or was his recording of another combination of notes? How do you know?
   Answers will vary depending on whether or not you gave them the "correct" order of wavelengths for their particular numbered set of tuning forks.

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