The Sound of Music

The sound of many musical instruments is the result of vibrations resonating within a column of air. Air column resonance is a topic of study in the field of physics. There are two basic types of air columns – referred to as **closed-end air columns** and **open-end air columns**. The difference depends on whether one or both ends of the column are open to the surrounding atmosphere.

Any column of air has a set of frequencies at which the air particles naturally vibrate. These frequencies are called **harmonics**; their value is dependent upon the length of the air column. The lowest frequency in the set is known as the **first harmonic**. Other frequencies in the set are whole number multiples of the lowest frequency. The mathematical relationship between the wavelength, frequency, and speed for the various harmonics is very predictable. **Table 1** illustrates these relationships for a 60-cm long closed-end air column. **Table 2** illustrates these same relationships for a 60-cm long open-end air column.

Table 1: Closed-End Air Columns

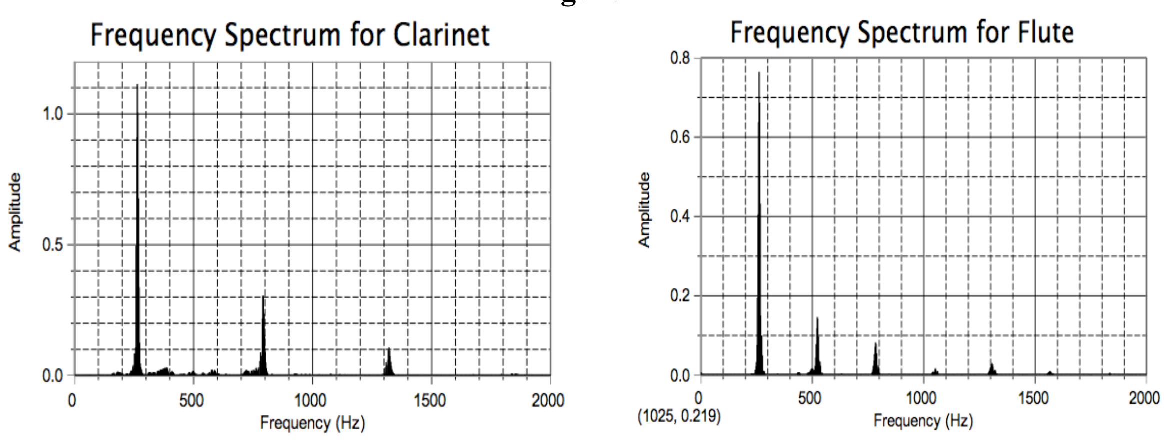
Harmonic	Frequency	Wavelength	Speed
1^{st}	142 Hz	2.40 m	340 m/s
3^{rd}	425 Hz	0.80 m	340 m/s
5^{th}	708 Hz	0.48 m	340 m/s
7^{th}	992 Hz	0.34 m	340 m/s

Table 2: Open-End Air Columns

Harmonic	Frequency	Wavelength	Speed
1^{st}	283 Hz	1.20 m	340 m/s
2^{nd}	567 Hz	0.60 m	340 m/s
3^{rd}	850 Hz	0.40 m	340 m/s
4^{th}	1133 Hz	0.30 m	340 m/s
5^{th}	1417 Hz	0.24 m	340 m/s

When a specific note is played on a musical instrument, the air particles immediately begin to vibrate with a set of many frequencies. These frequencies combine to produce the sound that we hear. Some of the frequencies within the set quickly dissipate and do not affect the overall sound. Other frequencies are sustained over time and become the prominent frequencies that affect the sound. These *enduring* frequencies are the harmonic frequencies. Two different instruments can play the same note, yet the resulting sounds can be quite different. A computer analysis of these sounds reveals that the difference has to do with the relative strength of the various harmonics that the instrument produces. The analysis results in a **frequency spectrum**. The spectrum shows the specific frequencies within the sound and their relative intensity or amplitude. Frequency spectra for a clarinet and a flute playing the note C_4 are shown in **Figure 1**.

Figure 1



Questions

1. What changes are observed in the speed of the harmonics of an open-end air column as the harmonic number is increased?
   a. The speed increases as harmonic number increases.
   b. The speed decreases as harmonic number increases.
   c. The speed first increases and then decreases as harmonic number increases.
   d. Changes in the harmonic number have no affect upon the speed of the harmonics.

2. Consider **Table 1**. How does the wavelength of the first harmonic of a closed-end air column compare to the length of the air column?
   a. The wavelength of the first harmonic is the same as the length of the air column.
   b. The wavelength of the first harmonic is two times the length of the air column.
   c. The wavelength of the first harmonic is four times the length of the air column.
   d. The wavelength of the first harmonic is one-fourth the length of the air column.

3. Consider **Table 2**. How does the wavelength of the first harmonic of an open-end air column compare to the length of the air column?
   a. The wavelength of the first harmonic is the same as the length of the air column.
   b. The wavelength of the first harmonic is two times the length of the air column.
   c. The wavelength of the first harmonic is four times the length of the air column.
   d. The wavelength of the first harmonic is one-half the length of the air column.

4. Consider **Table 1**. How does the frequency of the fifth harmonic compare to the frequency of the first harmonic?
   a. The two frequencies have the same value.
   b. The frequency of the fifth harmonic is five times greater.
   c. The frequency of the fifth harmonic is one-fifth the value of the first harmonic.
   d. An actual comparison cannot be made since there are other variables involved.

5. Use the pattern in **Table 1** to predict the frequency of the 9^{th} harmonic of a 60-cm long closed-end air column.
   a. Approximately 340 Hz　　b. Approximately 1140 Hz
   c. Approximately 1280 Hz　　d. Approximately 2040 Hz

6. Which one of the following variables does **NOT** affect the vibration frequency of air particles in an air column?
   a. The length of the air column.
   b. The amplitude of the harmonic.
   c. The harmonic number of the wave.
   d. Whether the air column is open or closed.

7. Which statement accurately compares the frequency of a harmonic in a closed-end air column to the frequency of the same harmonic in an open-end air column?
   a. The frequencies are the same for each.
   b. The frequencies are greater for the open-end air column.
   c. The frequencies are greater for the closed-end air column.

d. There is no clear pattern to how the frequencies compare.

8. Which statement accurately compares the wavelength of fifth harmonic for both types of air columns? Assume each air column has the same length.
   a. Their wavelengths are identical.
   b. The wavelength of the closed-end air column is 0.10 m longer.
   c. The wavelength of the closed-end air column is 0.18 m longer.
   d. The wavelength of the closed-end air column is two times longer.

9. Observe the three highest *spikes* in the frequency spectrum for the clarinet as shown in **Figure 1**. What is the frequency of the second most prominent peak?
   a. Approximately 260 Hz
   b. Approximately 520 Hz
   c. Approximately 790 Hz
   d. Approximately 1320 Hz

10. The *spikes* shown in the frequency spectrum in **Figure 1** represent the harmonic frequencies of the instrument. What are the frequencies of the three strongest harmonics for the flute?
    a. Approximately 260 Hz, 520 Hz, and 790 Hz.
    b. Approximately 260 Hz, 780 Hz, and 1320 Hz.
    c. Approximately 300 Hz, 500 Hz, and 700 Hz.
    d. Approximately 760 Hz, 140 Hz, and 90 Hz.

11. Consider the three most prominent *spikes* of the frequency spectrum for the clarinet shown in **Figure 1**. These spikes on the spectrum represent the harmonic frequencies of the clarinet. How does the frequency of the third spike compare to the frequency of the first spike?
    a. The third spike has a frequency that is about one-fifth the frequency of the first spike.
    b. The third spike has a frequency that is about one-tenth the frequency of the first spike.
    c. The third spike has a frequency that is about three times the frequency of the first spike.
    d. The third spike has a frequency that is about five times the frequency of the first spike.

12. Inspect the ratio of frequencies for the *spikes* of the clarinet's frequency spectrum in **Figure 1**. Compare it to the ratio of frequencies of the various harmonics shown in **Table 1** and **Table 2**. What is the evidence that exists that the clarinet consists of either a closed-end or an open-end air column?
    a. The clarinet consists of an open-end air column because all the harmonics are multiples of the first harmonic.
    b. The clarinet consists of an open-end air column because the height of the spikes in **Figure 1** is consistent with the pattern of the wavelengths in **Table 2**.
    c. The clarinet consists of a closed-end air column because the frequencies of the second and third spikes are three times and five times the frequency of the first spike.
    d. The clarinet consists of a closed-end air column because the ratio of the height of the spikes in **Figure 1** is consistent with the pattern of the wavelengths in **Table 1**.