

Lesson 4 – Natural Harmonics

Objectives

After completing this lesson you should

1. Know the natural modes of vibration of a plucked string of constant length and tension and the relationships between their frequencies.
2. Know what is meant by a bugle call.
3. Know at least one strategy for solving a counting problem.
4. Know the general names of the intervals on a piano keyboard.

Warm-Up Activity

Equipment:

- Several pieces of string or small-diameter rope, each about 5 feet long.
- Guitar or mono-chord.
- “Standing Wave Vibrations” resource sheet.

First and Second Harmonics

Your teacher will pluck a guitar string. When he/she does so, what you hear is a complex sound, but it is primarily the result of the most fundamental vibration pattern called the *first harmonic*. You can see a picture of the first harmonic on the resource sheet “Standing Wave Vibrations.”

Your teacher will now place his/her finger directly next to the string (in the middle) and instantly remove it when the string is plucked. Can you describe the difference in sound between this note and the first harmonic?

The vibration pattern that you are heard this time is called the *second harmonic*.

Assign two of your group members to hold opposite ends of the rope. A third group member should “pluck” the rope. First try to demonstrate the first harmonic. Then see if you can demonstrate the second harmonic. You may want to try to demonstrate the third harmonic, but be warned – it’s very difficult to do with a rope!

What do you think is the relationship between the frequencies of the first and second harmonics?

Other Harmonics

Fill in the frequencies for the second, third, fourth, and fifth harmonics on the “Standing Wave Vibrations” resource sheet.

The fractions of string lengths between nodes are terms of a famous mathematical sequence called the *harmonic sequence*: $\frac{1}{1}, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{1}{5}, \frac{1}{6}, \dots$

The notes above the first harmonic are called *overtones*. When a musical instrument sounds a note, the sound actually contains the fundamental and several overtones. In other words, the instrument actually produces vibrations in several different modes at the same time. The overtones account for the individual characteristics of different instruments. In other words, a clarinet has a characteristic set of overtones and a trumpet has a different set. The overtones are primarily responsible for the individual characteristics of each instrument’s sound or *timbre*.

The Piano Keyboard

Study the picture of the piano keyboard on the “Standing Wave Vibrations” handout. Be sure you are familiar with the names of the white keys. Note that C is always the note immediately to the left of the group of two black keys. Note that we start over again (with A) after G.

Go ahead and mark the lowest C in the picture with an f . (This note will be our fundamental in this example.) If this C is tuned to 130 hertz, then the C an octave higher will be tuned to twice this frequency or 260 hertz. Mark this C with $2f$. How should we mark the next C? (Hint: It’s *not* $3f$!)

Where should $3f$ go then? Obviously somewhere between $2f$ and $4f$, but where exactly? Well, it’s not at all obvious where it should go. However, by longstanding tradition in Western music, it goes on G. Similarly, $5f$ goes on the E above $4f$. Mark these frequencies now for future reference.

Intervals

Intervals on the piano keyboard are numbers which tell us how far apart the keys are. Remember when computing intervals that we always count **both** the starting and ending note. For purposes of this lesson, it will not be necessary to consider the black keys. If an interval spans **five** white keys, including the starting and ending key, then the interval is a **fifth**. If an interval spans **three** white keys, including the starting and ending key, then the interval is a **third**, etc.

Label each of the intervals in “Standing Wave Vibrations” with the appropriate interval name.

Music Notation

Here is music notation for the notes on the piano keyboard beginning with the C nearest the middle of the keyboard (called, logically, *middle C*).

The image displays two columns of musical notation, each containing six notes. Each note is represented by a treble clef on a five-line staff with a single quarter note. The notes are labeled with their respective letter names in red text to the right of the staff. The first column contains notes C, D, E, F, G, and A from top to bottom. The second column contains notes B, C, D, E, F, and G from top to bottom.

Bugle Calls

A bugle is a brass instrument similar to a trumpet, except that a bugle has no valves. Thus a bugle is a single-length tube. Here is a description of brass instrument sound production from

<http://www.exhibits.pacsci.org/music/Instruments.html>.

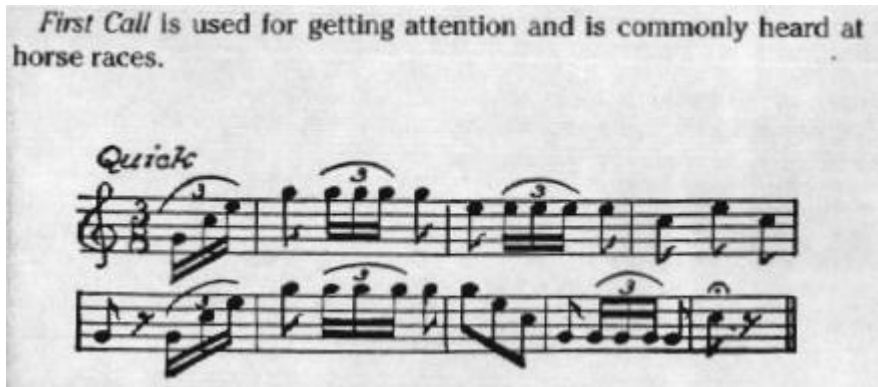
How the sounds are made

As with woodwinds, the sound comes from a vibrating column of air inside the tube of the instrument. The air column vibrates in resonance with the vibrating lips of the player, who presses her or his lips together in the mouthpiece and forces air out between them, making a "raspberry" or "Bronx cheer" sound.

How the pitch is changed

The pitch of a brass instrument depends on the volume of air that is vibrating, as well as the speed at which the player's lips vibrate. The volume of air depends on the length of the tube; a longer tube means a larger volume of air, hence lower pitch. By buzzing her lips faster or slower, the player can cause the air in the tube to resonate at different harmonics. With a single-length tube this yields only the notes found in bugle calls. To get all 12 notes of the chromatic scale, the player needs to change the length of the tube, as on the trombone, or play through different lengths of tubing, as on the brass instruments with valves.

Below are some well-known bugle calls (from http://www.usscouts.org/mb/bugle_calls.html). To what few notes are they all confined? Explain why these notes are attainable on a bugle and other notes are not.



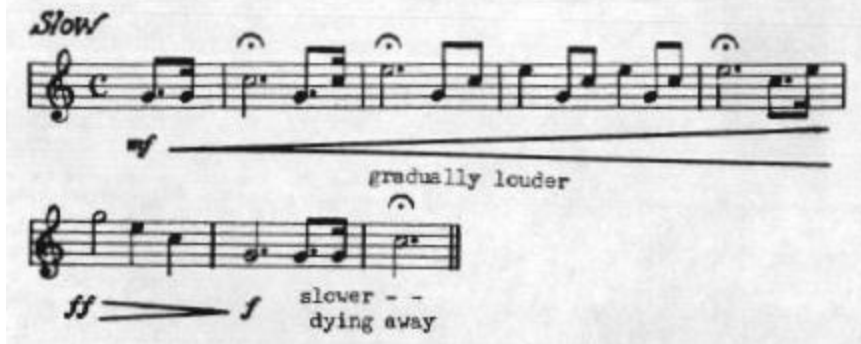
Reveille is the first call sounded in the morning and is used as a wakeup call.



To the Colors is played when everyone has gathered for the raising or lowering of the flag.



Taps signals the end of the day when everyone is to go to sleep. It also is played at funerals.



Homework

Give the general interval names for these intervals. In each case, the interval includes the first and last note listed.

1. From C to the next F above that C
2. From F to the next B above that F
3. From F to the next D above that F
4. From D to the next G above that D
5. From E to the next E

Suppose that a bugle call is to have two measures each consisting of two quarter notes. (In other words, the bugle call is to consist of four notes, each of the same duration. I know that's not very interesting rhythmically, but it will make a nice counting problem so let's go with it. Call the available notes G1, C, E, and G2.) Here are three examples of this type of bugle call:

C, C, C, C
 C, B, E, C
 G1, E, C, G2

1. List four more examples different from these.
2. How many such bugle calls are there?
3. Find a Web site from which you can listen to some bugle calls. Bring the web address to class.