MI-003 v1.0	**Title:** Copper Chimephone	**Target Grade Level:** 5-12	
Categories	Physics / Waves / Sound / Music / Instruments		**Pira** 3D
Standards	**US:** NSTA Science Content Std B, 5-8: p. 155, 9-12: p. 180		**VT:** S5-6:29
	Regional: McREL Science Standard 9, Levels II-IV		
Keywords	Resonance, Frequency, Pitch, Musical Instruments, Idiophone, Wavelength, Unclamped Beam , Timbre, Reflected wave, Standing Wave, nodes		
Project Type: Workshop	**Complexity:** Medium	**Materials:** Readily Available	
Project Duration: 0.5–1.0 hr Prep, 1.0 -1.5 hr Build		**Recommended Team Size:** 2-6	

Note: optional material is highlighted in red.

Workshop: Copper Chimephone

Purpose

The primary purpose of this project is to understand the connection between the length of an **unclamped beam** and its fundamental resonant frequency. This objective is accomplished by building and playing a xylophone-like instrument made from copper pipes. An optional goal is to develop an intuitive understanding of the mathematical relationship between the beam length and the frequency. Extensions of the project could include a discussion of the structure of musical scales.

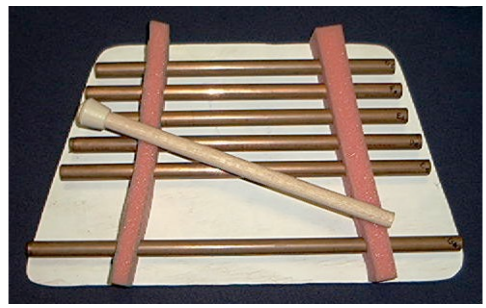


Fig. 1 Six-note copper chimephone with rubber-tipped beater

Background

A chimephone is a musical instrument in the **idiophone** (pronounced *`id·ē·ə·fōn*) category. The name idiophone comes from the Greek word *idios,* which means "one's own." Instruments of this kind are called idiophones because they make *their own* sound, depending on just the materials and shape of the object. Other idiophones include marimbas, tubular bells and the glockenspiel. The chimephones in this workshop consists of a grouping of copper tubes, each vibrating as an **unclamped beam**.

The **fundamental resonant frequency** of an object is the frequency that requires the lowest energy to cause the object to vibrate. If an unclamped beam is vibrated at frequencies that include the fundamental resonant frequency, the fundamental frequency will usually be the loudest sound produced. Assuming the fundamental frequency is in the audible range for humans, this frequency will be heard as the **pitch** of the beam.

In idiophones, higher resonant frequencies (**overtones**) may also be produced. Unlike the instruments in some other categories, these overtones do not have to be multiples of the fundamental frequency. The human ear may hear the overtones, but usually identifies the primary pitch as that of the fundamental frequency. The combination of the resonant frequencies is heard as a slight change which musicians refer to as the **timbre** (pronounced *`tam·bər*) of the instrument.

Materials & Tools

Materials per student:

(1) Copper tubing, Type M, ~1/2" (~1.3 cm) ID, 225–310 cm (7.5 ’–10’) long
(2) Foam strips, low density, 2 cm x 5 cm x 25 cm,
with 8 pre-drilled holes (See instructor Notes)
(1) Plywood support, ~1.3 cm x 25 cm x 45 cm (or equivalent)
(1) Dowel, 5/8” (~1.5 cm) OD, 30 cm long
(1) Rubber Chair leg cap, 5/8” (~1.5 cm)

Tools per student:

None required.

Tools per team:

(1) Pipe cutter
(1) Drill press vise, small
(1-3) Flat file(s)
(1) Masking tape, roll
(1-3) Tape Measure(s), metric
(1) Electronic tuner (or pitch-matching instrument)
(1) Pipe-length template (see Instructor Notes)

Tools for Instructor:

(1) Copper pipe, ½” (~13 mm) ID, with sharpened end (see Instructor Notes)
(1) Pair of scissors or knife for cutting foam (electric knives are the best)
(1) Oscilloscope, preferably with FFT frequency display (e.g., Winscope 2.51)

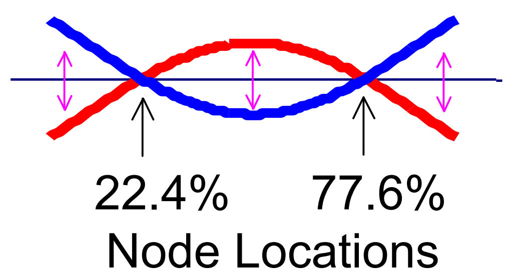
Procedure

(1) Slide the rubber chair-leg cap on the end of the wooden dowel to make the chimephone “beater.”

(2) Mark the longest tube length (from the data table) on a piece of copper pipe. Clamp the pipe in the drill press vise and cut it at the mark using the pipe cutter. Care should be taken to make sure the blade stays in the same track around the pipe during the cut. Use the flat file to remove any sharp projections from the cut pipe edge.

(3) Align the 2 pre-drilled foam strips on the plywood support, about 20 cm apart with the holes on the sides of the strips. Slide the long tube into the first hole of each strip so that about ¼ of the tube extends from each side.

The vibration of an unclamped beam at its fundamental frequency is illustrated at left. For an unclamped beam, the **nodes**, or the points that remain stationary, are located at 22.4 % and 77.6 % of the beam length. Why would these be good places to support the beam?



(4) Hit the middle of the pipe with the rubber end of the beater. Compare the resulting note to that of a reference instrument (e.g., electronic tuner, reference tube, another musical instrument).

a. If the pitch of the pipe is too low, then use the file to remove a small amount (e.g., ~0.5 mm) from the end of the pipe and re-check the pitch again. Repeat the process until the pitch is close to that of the reference instrument. Record the final length of the tube in the data table.

b. If the pitch of the tube is much too high, then the pipe is too short to be used for the note. It should be shortened to make the tube for the next higher frequency.

c. If the final tube lengths are found to be much different than those in the data table, a new set of starting lengths can be calculated after the length of one tube is tuned to the correct frequency.

New Length = Old Length x $(\text{Old Frequency})^2 / (\text{New Frequency})^2$

(5) Repeat steps (2) through (4) for each note in the table and slide the tubes into the foam strips in order of their length. Position the foam so that a quarter of each tube extends out each side (see Fig. 1).

Note	**Frequency (Hz)**	**Tube Length (cm)** Starting Value	Actual Value	**K Values ( )**	**Inverse Length^2 (cm^{-2})**
G_4	392.0	41.1			
A_4	440.0				
B_4	493.9				
C_5	523.2	35.6			
D_5	587.3	33.6			
E_5	659.2	31.8			
F_5	698.4	30.9			
G_5	784.0	29.2			
		Average K:			

(6) Using the relationship between frequency and actual tube length for vibrating beams, calculate the positions of the A_4 and B_4 notes.

Frequency = K / Length^2, where K is a constant

HINT: Solve for K for each length, average the K values and substitute into the equation to obtain the A_4 and B_4 lengths. Record the values in the table.

What are the units of K?

(7) If there are available materials, make the A_4 and B_4 tubes. Test and adjust them as described in steps (2) through (4).

(8) Calculate the inverse squares of the tube lengths and enter them into the appropriate column on the data table.

$$\text{Inverse Length}^2 = 1 / \text{Length}^2$$

(9) Plot the frequencies as a function of both the tube length and the inverse square of the length. Describe and explain the shape of the curves. Why would you want to plot the data as a function of inverse length squared?

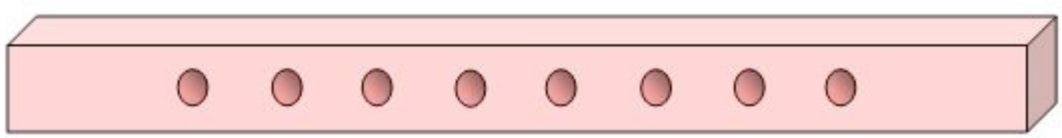
(10) If an oscilloscope with amplitude vs. frequency is available (see Tools for Instructor), strike one of the tubes with a rubber-tipped beater near a microphone connected to the oscilloscope. Identify the fundamental frequency and any overtones. Next, repeat the test but strike the tube with the wooden end of the beater. What do you notice?

(11) Become a chimephonist! Try to play a simple tune on your instrument. Even with just the six basic notes on your chimephone, you can play the first part of "Ode to Joy" by Beethoven. Ask your instructor for the music.

Instructor Notes

(1) Low density foam is a commonly used packing material. Cutting it into the correct strips can be accomplished with scissors or a sharp knife. However, an electric knife is by far the best tool for this job.

(2) A line of eight ½" holes should be pre-drilled into the sides of each foam strip. This can be accomplished by using a section of the ½" copper pipe with one end slightly sharpened with the flat file. To drill the hole, the sharpened pipe is pressed gently against the foam and rotated until the foam is penetrated. Care should be taken to keep fingers away from the sharp edge of the pipe. The process can be simplified by mounting a short section of sharpened pipe in a drill press.

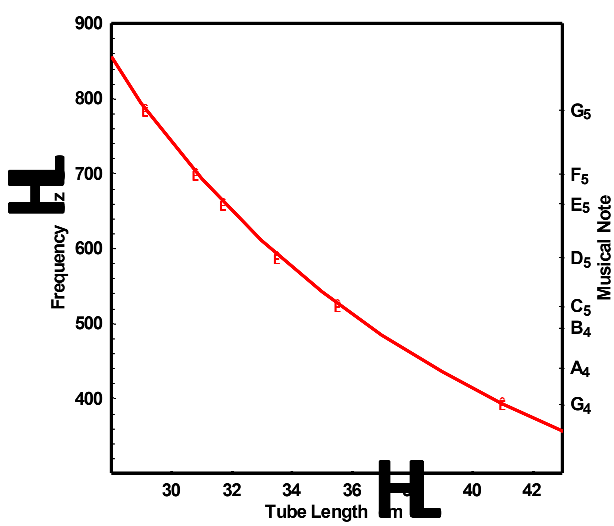


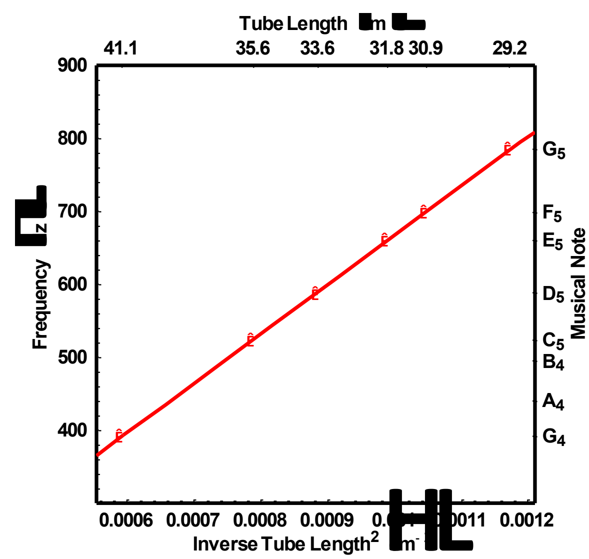
(3) A tube-length template can be made from a section of ¾" CPVC tubing with an end cap glued on one end. Holes are drilled through the wall of this tube so that they can be used to mark the correct lengths of ½" copper pipe when inserted into the CPVC tube. The length of the CPVC tube is that required to mark the longest copper pipe. In practice, the shortest tubes should be cut first so that they are more easily marked. Use of this template can be used to demonstrate a method for simplification of the fabrication process. However, variations in

the copper pipe (e.g., wall thickness) may require different hole locations for each batch of copper pipe. Some experimentation with each batch of copper pipe is recommended before the workshop.

(4) Table values and sample frequency vs. tube length plots are shown below.

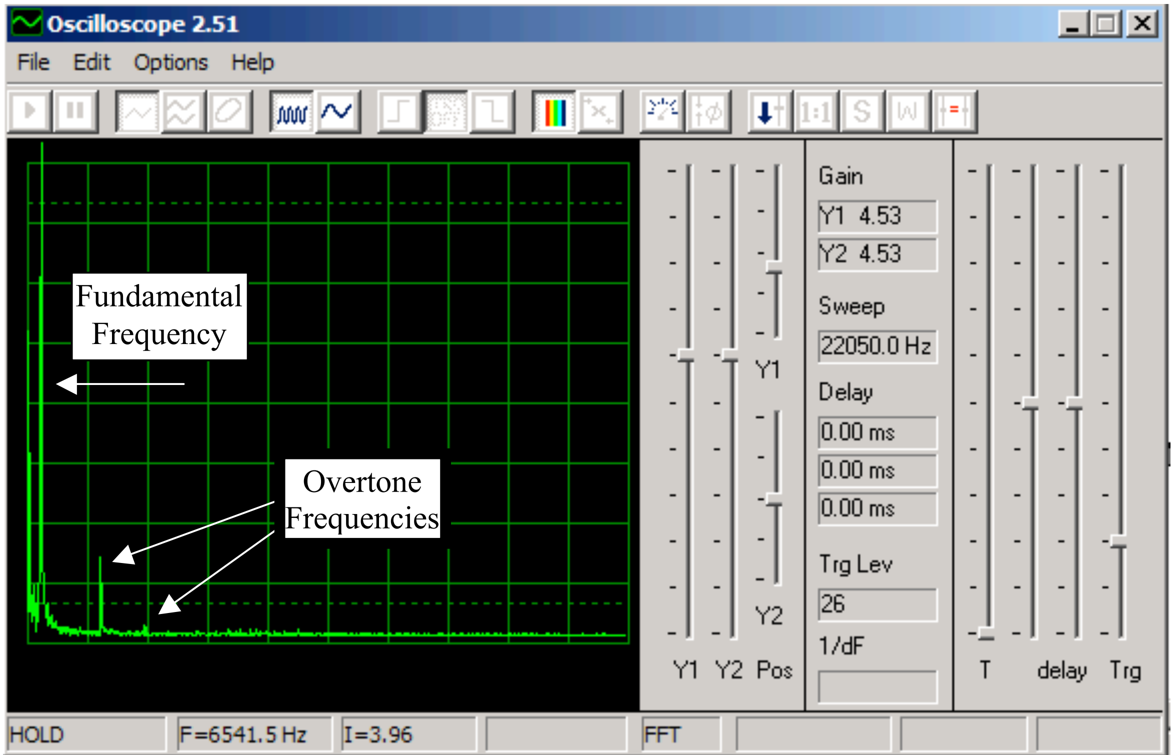
Note	Frequency (Hz)	Length (cm)	K Values (cm^2/s)	Inverse Length^2 (cm^{-2})
G_4	392.0	41.1	662170	5.92×10^{-4}
A_4	440.0	38.9	-	?
B_4	493.9	36.7	-	?
C_5	523.2	35.6	663083	7.89×10^{-4}
D_5	587.3	33.6	663038	8.86×10^{-4}
E_5	659.2	31.8	666609	9.89×10^{-4}
F_5	698.4	30.9	666839	1.05×10^{-3}
G_5	784.0	29.2	668470	1.17×10^{-3}
		Average K:	665035	





(5) There are numerous free oscilloscope software packages available on the internet. If a package with amplitude vs. frequency plotting capability can be obtained, it is useful in identifying the fundamental and harmonic frequencies of most instruments.

A sample display from Winscope 2.5.1 (by Konstantin Zeldovich) is shown below for a C_5 note from a copper chimephone struck with a rubber-tipped beater.



The frequency display for the same tube struck with the wooden end of the beater is shown below. Note the increased number of exited frequencies and the reduced fundamental height.