| MI-002 v1.0 | Title: Pan Pipes | 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, Aerophone, Wavelength, Closed Tube, Timbre, Reflected wave, Standing Wave | | |
| Project Type: Workshop | Complexity: Easy | Materials: Readily Available | |
| Project Duration: 0.5–1.0 hr Prep, 0.5-1.0 hr Build | | Recommended Team Size: 2-6 | |

Note: optional material is highlighted in red.

# Workshop: Pan Pipes

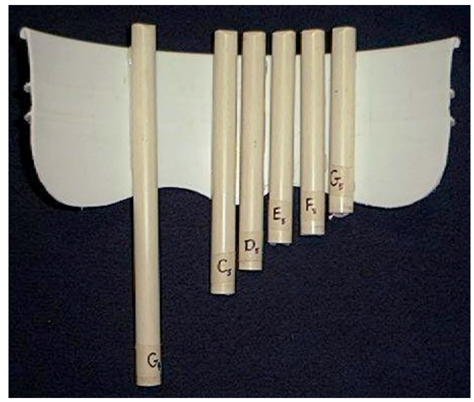


Fig. 1 Six-note pan pipes glued to a rigid frame

## Purpose

The primary purpose of this project is to understand the connection between the length of a **closed tube** and the fundamental resonant frequency of its air chamber. This objective is accomplished by building and playing a set of pan pipes made from CPVC tubes. An optional goal is to develop an intuitive understanding of the mathematical relationship between the tube length and the frequency. Extensions of the project could include a discussion of the structure of musical scales.

## Background

A set of pan pipes is a musical instrument in the **aerophone** category. Aerophones, commonly referred to as wind instruments, produce sounds by vibrating the air in a hollow object. For the pan pipes in this workshop, the hollow objects are short lengths of CPVC tubes. Other aerophones include flutes, oboes and trumpets.

The **fundamental resonant frequency** of a material is the frequency that requires the lowest energy to cause the material to vibrate. If the air within a tube 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 object.

In aerophones, multiples of the fundamental frequency (**harmonics** or **overtones**) may also be produced. The human ear may hear these sounds, but usually identifies the primary pitch as that of the fundamental frequency. The combination of the harmonic frequencies is heard as a slight change which musicians refer to as the **timbre** (pronounced `*tam·bər*) of the sound.

## Materials & Tools

**Materials per student:**
(1) CPVC pipe, ~1.3 cm (0.5 in) ID, 100 – 150 cm long
(6-8) ~1.3 cm OD corks or plugs cut from a ~2.5 cm-thick (1 in) Styrofoam board
(1) Sheet for recording data (e.g., cork positions)

**Tools per student:**
(1) Dowel, ~1 cm (3/8 in) OD, ~30 cm long

**Tools per team:**
(1) Pipe cutter
(1) Flat file
(1-3) Ruler(s), metric
(1) Packing tape or duct tape, roll
(1) Electronic tuner (or pitch-matching instrument)
(1) Tube-length template (see Instructor Notes)

**Tools for Instructor:**
(1) Dowel, ~1 cm (3/8 in) dia., ~30 cm long, marked with cork positions for each note
(1) Oscilloscope, preferably with FFT frequency display (e.g., Winscope 2.51)

## Procedure

(1) Using the pipe cutter, cut tubes to the lengths shown in the attached table. Wrap a piece of masking tape around the bottom of each tube and mark it with the musical note corresponding to each length.

(2) Insert a cork just inside the bottom end of each tube.

(3) To play each tube, place your bottom lip on the near side of the top of the tube and blow across and slightly downward. Optimize the angle and width of the air stream to get the best tone.

(4) Compare the note to a reference instrument (e.g., electronic tuner, reference tube, another musical instrument). With your fingers or the dowel, adjust the cork position to match the reference tone. Measure the cork positions by inserting the dowel, marking the depth of the cork on the dowel and measuring the marked distance with the ruler. Record the positions in the data table.

| Note | Frequency (Hz) | Tube Length (cm) | Cork Position (cm) | K Values (        ) | Inverse Length ($mm^{-1}$) |
|---|---|---|---|---|---|
| $G_4$ | 392.0 | 23.2 | 20.3 | | |
| $A_4$ | 440.0 | | | | |
| $B_4$ | 493.9 | | | | |
| $C_5$ | 523.2 | 17.6 | 14.8 | | |
| $D_5$ | 587.3 | 15.8 | 12.9 | | |
| $E_5$ | 659.2 | 14.3 | 11.4 | | |
| $F_5$ | 698.4 | 13.6 | 10.5 | | |
| $G_5$ | 784.0 | 12.2 | 9.2 | | |
| | | | Average K: | | |

(5) Using the relationship between frequency and actual tube length, calculate the position of the $A_4$ and $B_4$ notes.

Frequency = K / Length, where K is a constant

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

What are the units of K?

(6) If there are available materials, make the $A_4$ and $B_4$ pipes. Test and adjust them as described in step (7).

(7) Align the tubes about 2 cm apart with the longest on the left. Tape them together with a packing or duct tape. This step may be more easily accomplished by first laying a piece of tape on a table (sticky side up), aligning the tubes on it, and then applying another piece of tape across the top. If desired, the tubes can be taped or glued to a rigid frame instead.

(8) Calculate the inverse values of the cork positions and enter them into the appropriate column on the data table.

Inverse Cork Position = 1/ Cork Position

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

(10) If an oscilloscope with amplitude vs. frequency is available (see Tools for Instructor), play one of the tubes into a microphone connected to the oscilloscope and observe the result. Identify the fundamental frequency and any harmonics.

(11) Become a pan piper! Try to play a simple tune on your instrument. Even with just the basic six notes in your pan pipes, you can play the first part of "Ode to Joy" by Beethoven.

# Instructor Notes

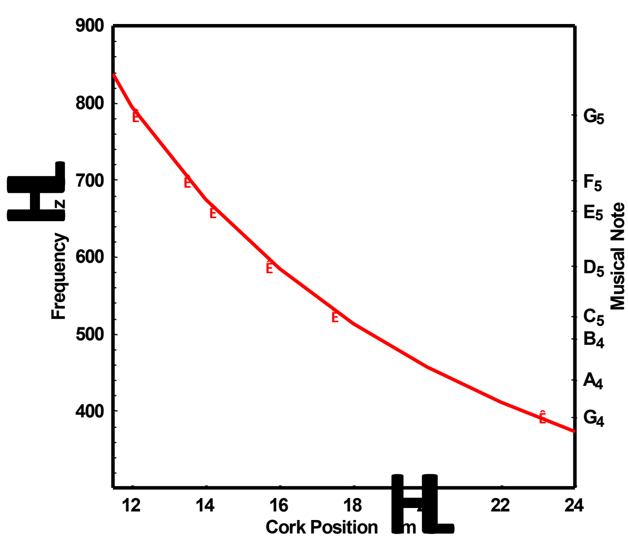
(1) A tube-length template can be made from a section of ¾" CPVC tubing with an end cap glued on one end. Holes are drilled through the wall of this tube so that they can be used to mark the correct lengths of ½" pan-pipe tubing when inserted into the larger tube. The length of the ¾" tube is that required to mark the longest 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.

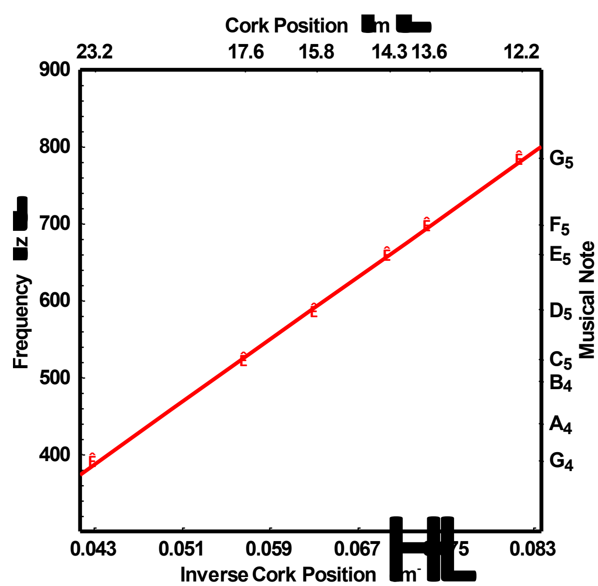
(2) A slight bevel at the top edge of the pipe, as shown in Figure 1, may improve sound quality. A flat file may be used to produce the bevel. Some experimentation is required. Make sure to remove any plastic debris that may result.

(3) A more finished instrument can be produced by attaching the tubes to a rigid frame. A slight curvature of the frame is desirable for easier note changes. Possible frame materials include sections cut from the side of 5-gallon plastic buckets (e.g., joint compound buckets).

(4) Sample table values and frequency vs. cork position plots are shown below.

| Note | Frequency (Hz) | Tube Length (cm) | Cork Position (cm) | K Values ( cm/s ) | Inverse Length (mm$^{-1}$) |
|---|---|---|---|---|---|
| $G_4$ | 392.0 | 23.2 | 20.3 | 9094 | $4.31 \times 10^{-2}$ |
| $A_4$ | 440.0 | 24.2 | 21.2 | - | - |
| $B_4$ | 493.9 | 21.9 | 18.9 | - | - |
| $C_5$ | 523.2 | 17.6 | 14.8 | 9208 | $5.68 \times 10^{-2}$ |
| $D_5$ | 587.3 | 15.8 | 12.9 | 9279 | $6.33 \times 10^{-2}$ |
| $E_5$ | 659.2 | 14.3 | 11.4 | 9426 | $6.99 \times 10^{-2}$ |
| $F_5$ | 698.4 | 13.6 | 10.5 | 9498 | $7.35 \times 10^{-2}$ |
| $G_5$ | 784.0 | 12.2 | 9.2 | 9565 | $8.20 \times 10^{-2}$ |
| | | | Average K: | 9345 | |



(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 $D_5$ note played on a pan pipe.