MI-002 v1.0	**Title:** PVC Flute	**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:** Medium	**Materials:** Readily Available	
Project Duration: 0.5–1.0 hr Prep, 1.0 hr Build		**Recommended Team Size:** 2-6	

Note: optional material is highlighted in red.

Workshop: PVC G Flute

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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 flute made from a CPVC pipe. 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.

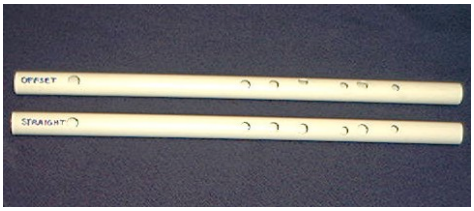


Fig.1 PVC G-flutes with straight and off-set holes

Background

A flute is a musical instrument in the **aerophone** category. Aerophones, commonly referred to as wind instruments, produce sounds by vibrating the air inside a hollow object. For the flute in this workshop, the hollow object is a short length of PVC pipe. Other aerophones include pan pipes, 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 small change which musicians refer to as the **timbre** (pronounced *`tam·bər*) of the instrument. It is the difference in timbre that makes the same pitch on a flute and a violin sound different.

Materials & Tools

Materials per student:
(1) PVC Schedule 40 pipe, 1/2" (~1.5 cm ID), 18.5" (47 cm) long
(1) ~1.6 cm OD cork or plugs cut from a ~2.5 cm-thick (1 in) Styrofoam board
(1) Sheet for recording data (e.g., hole positions)

Tools per team:
(1) Half-round file, very small
(1-3) Nail(s), sharp
(1-3) Hammer(s), small
(1-3) Hand drill(s)
(1-3) Set(s) of drill bits (5/16", 3/8")
(1-3) Drill press vise
(1-3) Pipe clamps
(1-3) Goggles
(1) Hole-template tube (See Instructor Notes)
(1) Masking tape, roll
(1) Electronic tuner (or pitch-matching instrument)

Tools for Instructor:
(1) Pipe cutter
(1) Galvanized pipe, 1 end sharpened, 5/8" (~1.6 cm) ID, 10 cm long
(1) Oscilloscope, preferably with FFT frequency display (e.g., Winscope 2.51)

Procedure

(1) Try out the sample flutes with offset and straight finger holes. Hold the middle of the flute with your left hand and the far end with your right. Your finger tips should be near the 6 note holes. Turn the flute so that the side of the mouth hole is just in front of your mouth. Your hands should be raised to your chin level and positioned slightly to your right. Select the hole pattern that is most comfortable for you in this position.

(2) Table 1 lists the hole positions for a flute in the key of G except for A_4 and B_4. Using the relationship between frequency and tube length, calculate the position of the A_4 and B_4 holes (the length between the nearest edges of the mouth hole and the note holes).

Frequency = K / Edge-to-edge Length, where K is a constant

HINT: Solve for K for each length, average the K values and substitute into the equation to find the hole positions for the A_4 & B_4 notes. Record the values in the table.

What are the units of K?

Table 1 Flute Hole Position Data

Note	Frequency (Hz)	Hole Center Position (cm)	Edge-to-edge Length (cm)	K Values ( )	Inverse Length (mm^{-1})
G_4	392.0	0 (tube end)	405.7		
A_4	440.0				
B_4	493.9				
C_5	523.2	128.0	273.8		
D_5	587.3	166.5	235.3		
E_5	659.2	200.0	201.8		
$F^{\#}_5$	740.0	229.5	172.3		
Mouth	---	410.5	---	---	---
			Average K:		

(3) Use the template tube to mark the hole positions on the flute pipe (see Figure 2). Measure and mark the location of the A_4 and B_4 holes for the hole pattern that you selected. If you picked the offset hole pattern, move the B_4 mark 0.2 cm above the line. Have your instructor check the A_4 and B_4 hole positions.

(4) Using the nail and small hammer, make a small dent in the tube at the center of each of the marked holes.

(5) Clamp the tube in the drill-press vise so that the dent for the first note hole is located at the top and center of the vise. Take off any necklaces and bracelets and make sure long hair is tied back.

(6) Put a 5/16" drill bit into the hand drill (or drill press), tighten it and put on goggles. Drill a hole through just the top side of the tube… WHEN THE DRILL PENETRATES THE TOP WALL OF THE TUBE, THE DRILL WILL JUMP AND IT WILL BE MORE DIFFICULT TO CONTROL. Be careful not to drill into the bottom wall of the tube. Repeat this step for all the note holes.

(7) Change the drill bit to 3/8" and drill the mouth hole. Since the drill bit has a larger diameter, the rotation force, or **torque**, will be larger and the drill will be even more likely to jump when the drill bit penetrates the tube wall.

(8) Clean up any ragged edges with a small file. Shake out any debris left inside the tube. Rinsing and drying the tube is also recommended to remove any small particles.

(9) Insert a cork just inside the mouth end of the tube. Do not let it block the mouth hole.

(10) Calculate the inverse values of the hole positions (the distance between the nearest edges of the mouth hole and the note holes) and enter them into the appropriate column on the data table.

Inverse Hole Position = 1/ Hole Position

(11) Plot the frequencies as a function of both the hole 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?

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

(13) Flout your flute and become a flutist!

a. Hold the middle of the flute with your left hand and the far end with your right. Turn the flute so that the mouth hole is in front of your mouth. Your hands should be raised to your chin level and positioned slightly to your right.

b. Without covering any note holes, place your bottom lip on the near side of the mouth hole and blow across and slightly downward. Optimize the angle and width of the air stream to get the best tone. It takes a while to master this technique, but after you do, the flute is relatively easy to learn to play.

c. Different notes are played by covering the holes starting with the one nearest the mouth hole and then covering additional holes until they are all covered. A chart showing the finger positions for each note is shown in Figure 3.

(14) Even with just six notes, you can play the first part of "Ode to Joy" by Beethoven. Ask your instructor for the music.

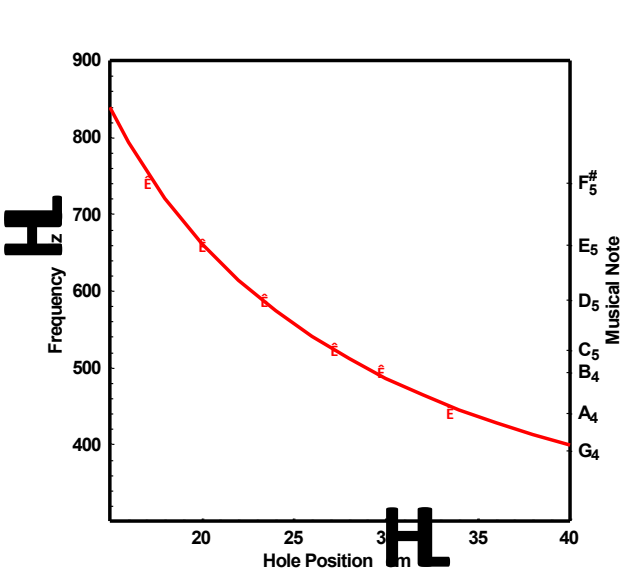
Instructor Notes

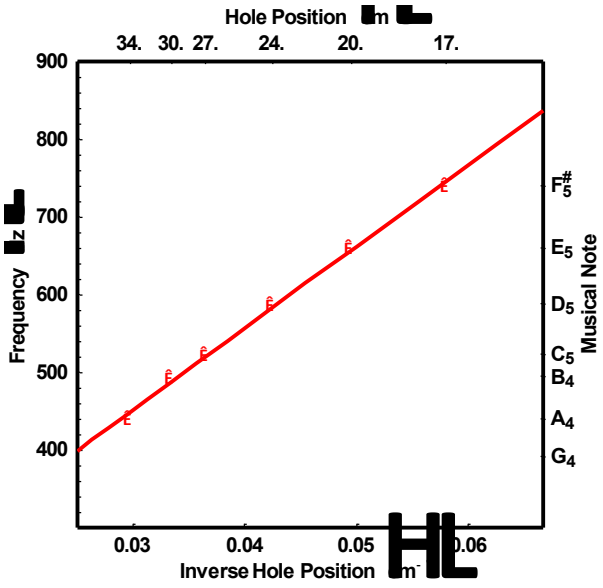
(1) A tube-length template can be made from a section of 1" CPVC tubing with an end cap glued on one end. Holes are drilled through the wall of this tube so that they can be used to mark the correct lengths of ½" PVC flute tubing when inserted into the larger tube. The length of the 1" CPVC tube is that required to mark the length of the flute. Use of this template can be used to demonstrate a method for simplification of the fabrication process.

(2) Sample table values and frequency vs. hole position plots are shown below.

Table 1 Flute Hole Position Data

Note	Frequency (Hz)	Hole Center Position (cm)	Edge-to-edge Length (cm)	K Values ( )	Inverse Length (mm^{-1})
G_4	392.0	0 (tube end)	405.7		
A_4	440.0	65.5	336.3		
B_4	493.9	103.0	298.8		
C_5	523.2	128.0	273.8		
D_5	587.3	166.5	235.3		
E_5	659.2	200.0	201.8		
$F^{\#}_5$	740.0	229.5	172.3		
Mouth	---	410.5	---	---	---
			Average K:		





(3) 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 A_4 note played on a PVC flute.