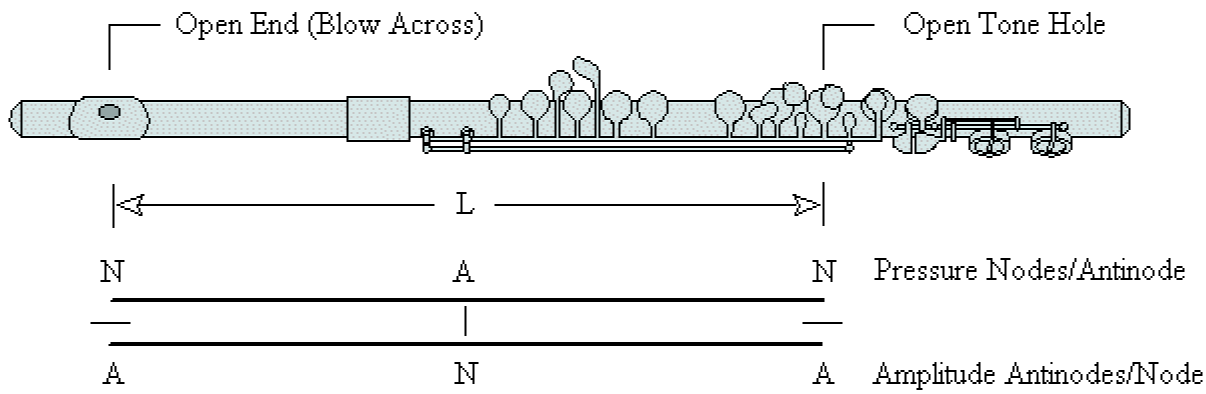
W. Woodwinds

We now take up the study of the musical instruments. We consider in this chapter and the next two, the three main sections of the orchestra: woodwinds, brass, and strings. We choose this order because it corresponds to the manner in which they appear on an orchestral score of music. In the chapter on strings, we discuss percussion, which is also very important.

Flutes

1. Flute: The Physics. The flute is an open pipe. Fig. W-1 illustrates an orchestral flute. The player blows across the left end. It serves as one of the open ends of the pipe. The other open end is determined by which tone hole is open. The effective length of the open pipe changes. Fig. W-1 leads us step by step in arriving at the length needed for a mid-range tone, E_4. The value for the speed of sound at freezing temperatures is used to simplify the arithmetic. This is okay since we are after an approximate answer anyway. It is interesting to discover that the length is approximately 50 cm, a length that humans can carry.

Fig. W-1. Flute.



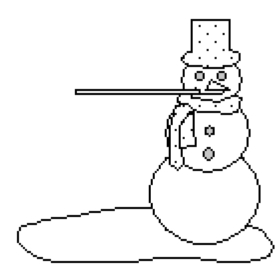
For the Fundamental: $\lambda / 2 = L$ $\lambda f = v = 340$ m/s

Example calculation: What is L for E_4, i.e., 330 Hz?

Step 1. Find Wavelength from Frequency: $\lambda f = 330$ m/s (Use speed at 0°C, 32°F.)

λ (330 Hz) = 330 m/s

$\lambda = 1$ m



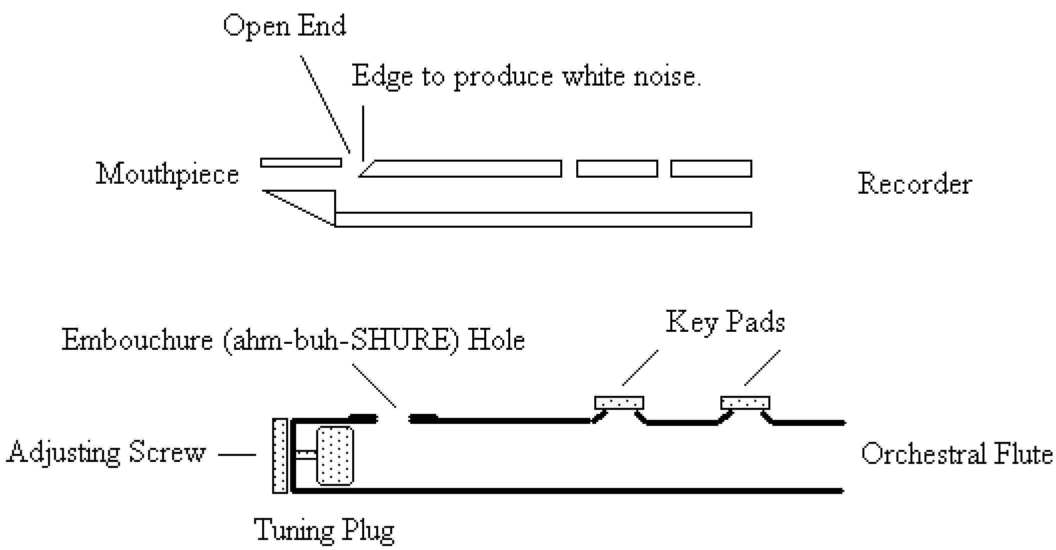
Step 2. Find Pipe Length from Wavelength: $L = \lambda / 2$

$L = (1 \text{ m}) / 2 = 0.5 \text{ m} = 50 \text{ cm}$

2. Flute: Producing the Tones in the Scale. Twelve effective lengths of the pipe are needed to obtain the 12 tones in the chromatic scale. One length is achieved by using the far end of the open pipe. Then, 11 tone holes are needed to produce shorter "effective pipe lengths" to obtain the other 11 pitches. The orchestral flute has a few additional holes to make playing easier. The tone holes provide for notes within one octave. Driving the pipe to resonate at higher harmonics extends the range. Fig. W-2 illustrates an older flute (the recorder) and the orchestral flute.

Many common variety flutes resemble the recorder. You blow into one end and use your fingers to cover holes. To open a hole, a finger is released. The number of holes needs to be reduced unless you have 12 fingers. The author had a toy flute with 8 holes in 5th grade. The additional tones in the chromatic scale could be produced by using the technique of covering half a hole.

Fig. W-2. Recorder and Orchestral Flute.

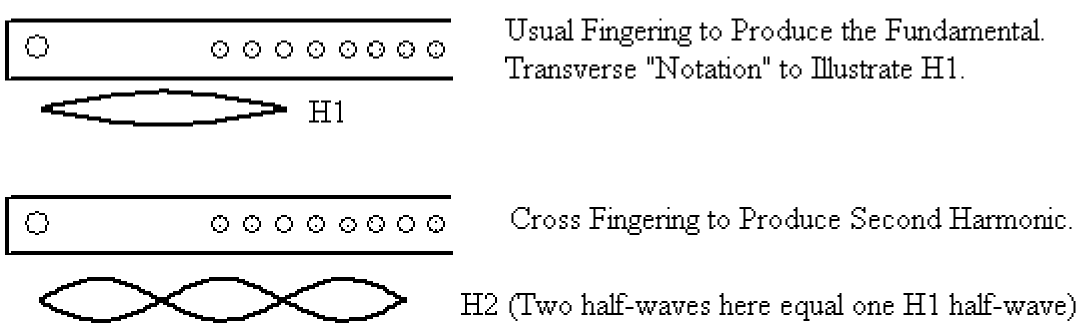


The source of energy for the flute is supplied by the jet of air made by the player. Blowing across the embouchure of an orchestral flute produces white noise. The pipe goes into resonance. Putting the mouth completely over the mouthpiece in the case of the recorder presents a problem. The air stream travels straight through the tube like a straw, unless there is an edge with another opening to produce turbulence. The air flow coming into contact with the edge produces the resonance.

The orchestral flute has a tuning plug that enables the player to slightly change the length of the flute. The change in pipe length shifts the frequency slightly. The resonance is affected by the blowing pressure, air-jet length, and area of lip opening. The player can control the sound level in this way. The pitch can either be slightly modified by these or drastically by exciting a higher harmonic.

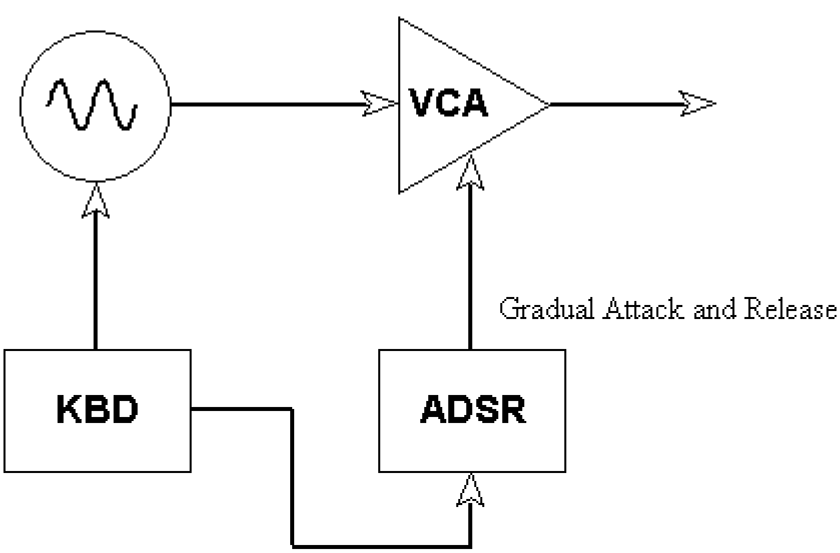
3. Flute: Extending Musical Range. The flutist can also obtain higher pitches by carefully arranging for additional openings to encourage more nodes. This technique is called cross fingering. In Fig. W-3 there is an extra key pad raised. The node positions support a pipe resonance at the second harmonic (H2). Here 2 half-waves fit into the same length (lower diagram) compared to the one half-wave of H1 (upper diagram). This technique and the earlier ones mentioned allow coverage of the 3 octaves C_4 to C_5, C_5 to C_6, and C_6 to C_7.

Fig. W-3. Cross Fingering to Excite Next Harmonic.



4. Flute: Synthesis. A flute-like sound can be synthesized using a sine wave (see Fig. W-4). The synthesized sound is approximate; however, not bad for imitating a toy flute. Improvements can be made by adding a little white noise to the sound to imitate breath and another oscillator to add a touch of the first overtone. These additions require more modules and a mixer.

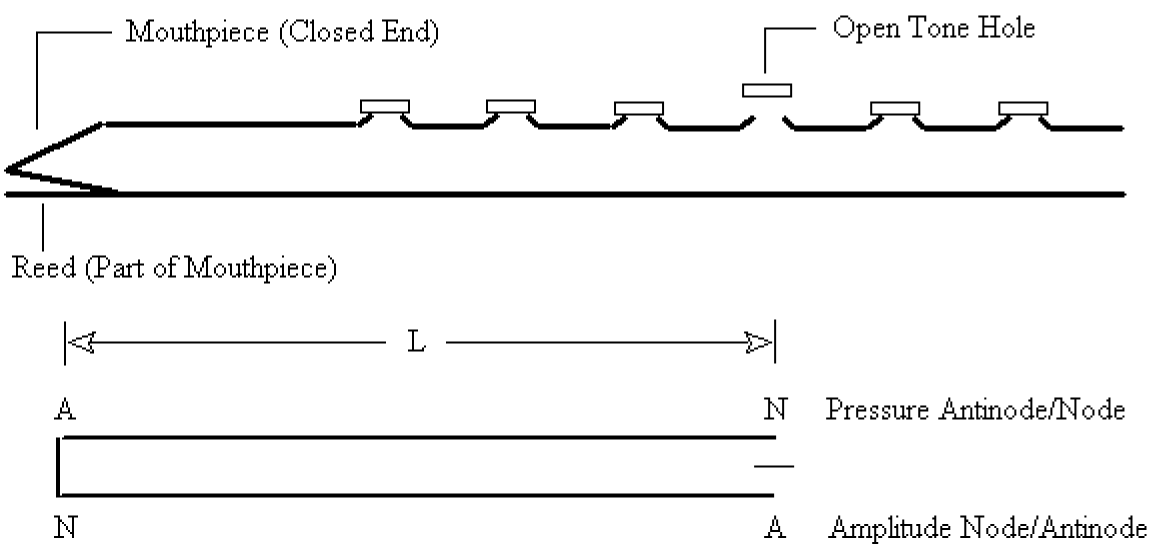
Fig. W-4. Synthesizing a Flute-Like Sound.



Clarinets

1. Clarinet: The Physics. The clarinet mouthpiece is different from the flute. The player's mouth covers the end of the mouthpiece on the clarinet. Therefore, this end is closed. Fig. W-5 illustrates modeling the clarinet as a closed model. The reed vibrates, supplying the energy for the resonance. The effective length of the closed pipe is from the mouthpiece to the opening at the tone hole in Fig. W-5. The wavelength for the fundamental is given as 4L for a closed pipe of length L since one quarter-wave fits along the pipe length. The fundamental frequency produced is one octave lower than that for an open pipe of the same length. Therefore, the E_4 (330 Hz) we obtained with a 50-cm open pipe in the flute analysis now drops an octave lower to E_3 (165 Hz) for a closed pipe of the same length. Details of the explicit calculation are found in Fig. W-5.

Fig. W-5. Clarinet Schematic.



For the Fundamental: $\lambda / 4 = L$ $\lambda f = v = 330$ m/s (Freezing Temperature)

Example calculation: Find the frequency if L = 50 cm (the length for E_4 on the flute).

Step 1. Find Wavelength from Pipe Length: $\lambda / 4 = L = 50$ cm

$\lambda = 4L = 200$ cm

$\lambda = 2$ m

Step 2. Find Frequency from Wavelength: (2 m) f = 330 m/s (using $\lambda f = v = 330$ m/s)

f = 165 Hz (Octave lower than the flute case.)

2. Clarinet (Fig. W-6): Producing the Tones in the Scale. For an open-pipe instrument, 11 tone holes and the 1 all-tone-holes-shut position cover the 12 notes of the chromatic scale. Higher harmonics are produced to reach into the next octave or two.

There is a problem with a closed pipe since the next harmonic is the third harmonic, not the second. Therefore we need tone holes to span the notes from H1 to H3. Fig. W-7 illustrates the physics of tone holes for open and closed pipes. The total pipe length (all holes shut) is used for the lowest note. The tone holes are needed to fill in the notes in between H1 and H2 for open pipes, H1 and H3 for closed.

Fig. W-6. Clarinet

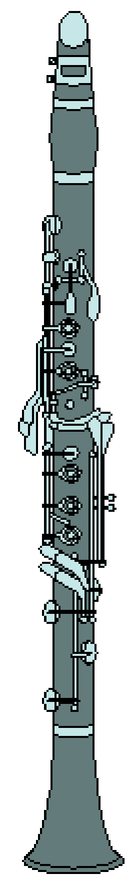


Fig. W-7a. Tone Holes Needed for Open Pipe (11).

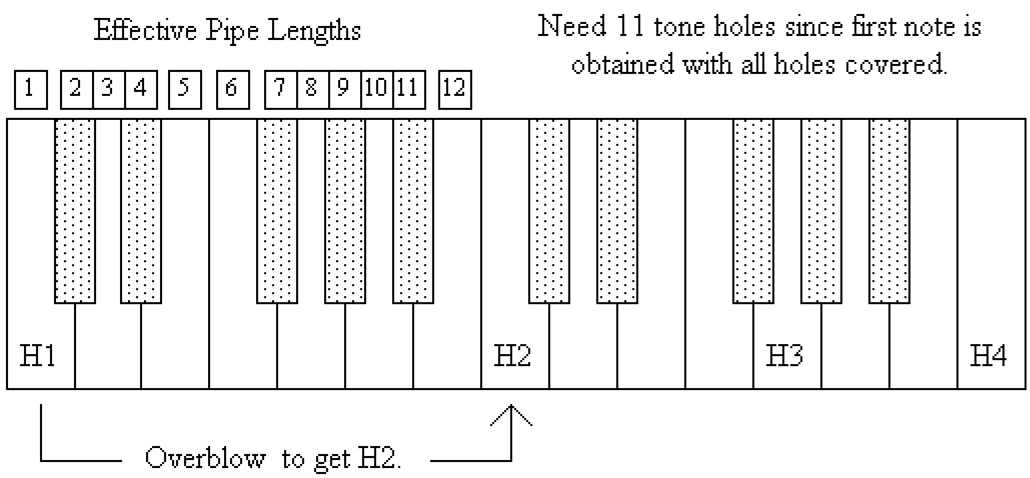
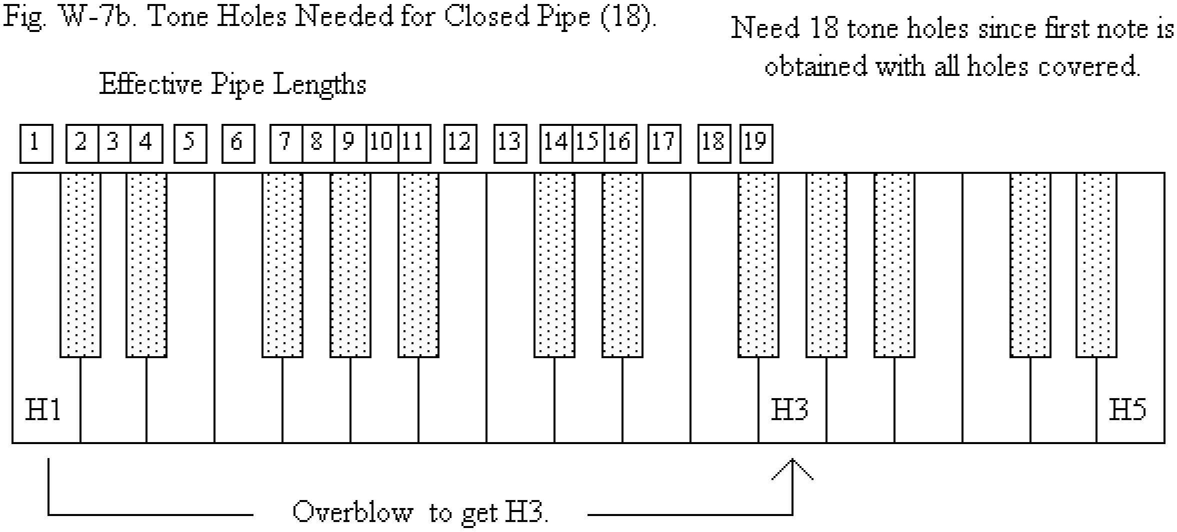
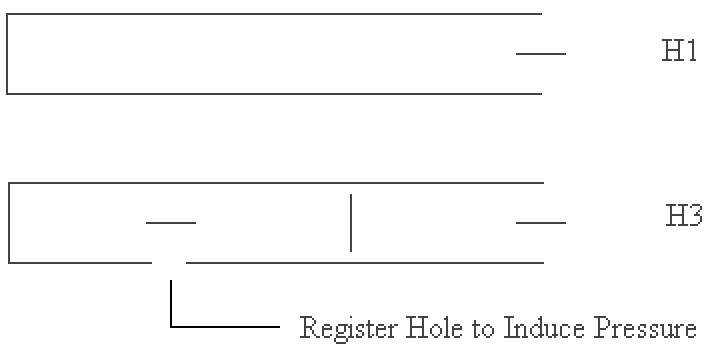


Fig. W-7b. Tone Holes Needed for Closed Pipe (18).



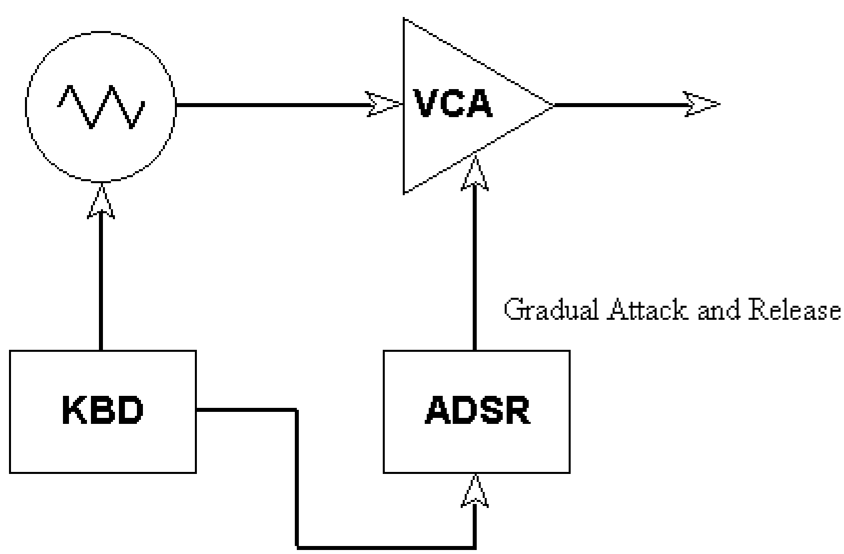
3. Clarinet: Extending Musical Range. The clarinetist gets assistance from a register hole to produce the third harmonic (see Fig. W-8). Cross fingering is also used to play in the higher octaves. The combination of these and blowing techniques enable the clarinet to extend to 3 octaves. The common orchestral clarinet, the B-flat clarinet, easily spans the 3 octaves D_3 to D_4, D_4 to D_5, and D_5 to D_6. The first note D_3 is almost an octave lower than the flute's first note C_4.

Fig. W-8. Register Hole to Induce The Third Harmonic.



4. Clarinet: Synthesis. To synthesize a clarinet-like sound, we first note that the clarinet functions, in our model, as a closed pipe. Closed pipes produce odd harmonics. The resonance in the lowest register consists mainly of the fundamental. To achieve a fundamental with some small presence of odd overtones, we use a triangle wave or square wave. The Fourier spectra for these contain only odd harmonics.

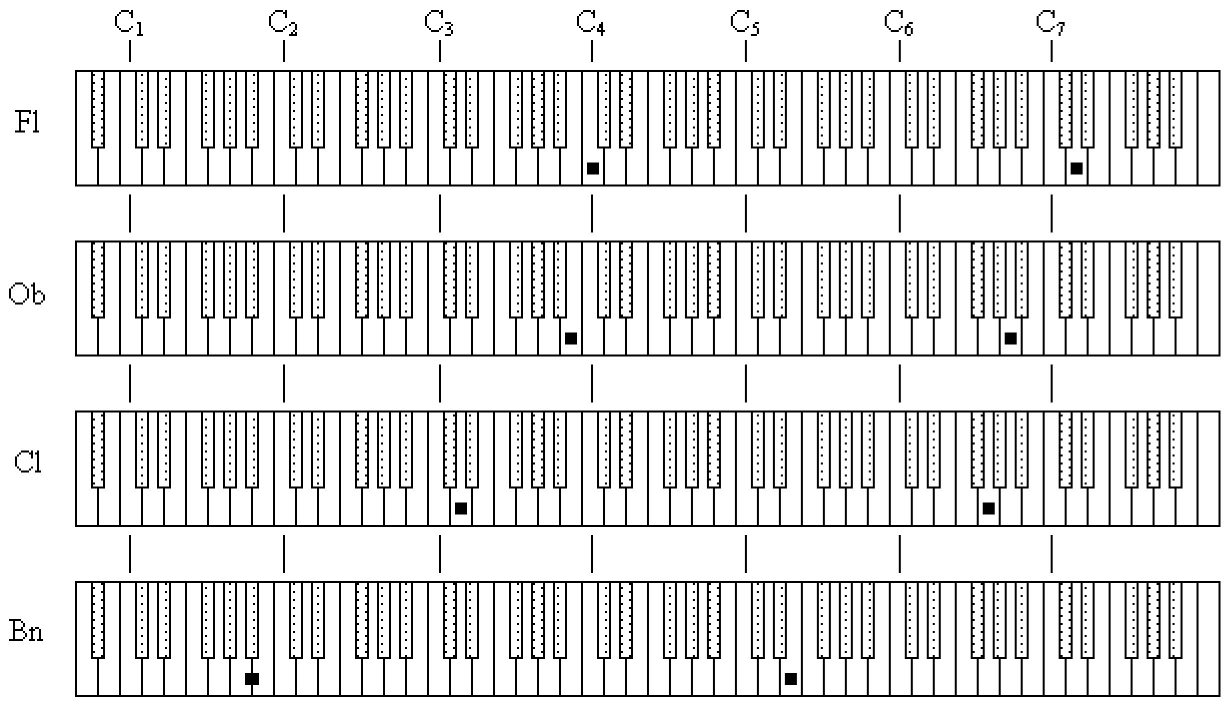
Fig. W-9. Synthesizing a Clarinet-Like Sound.

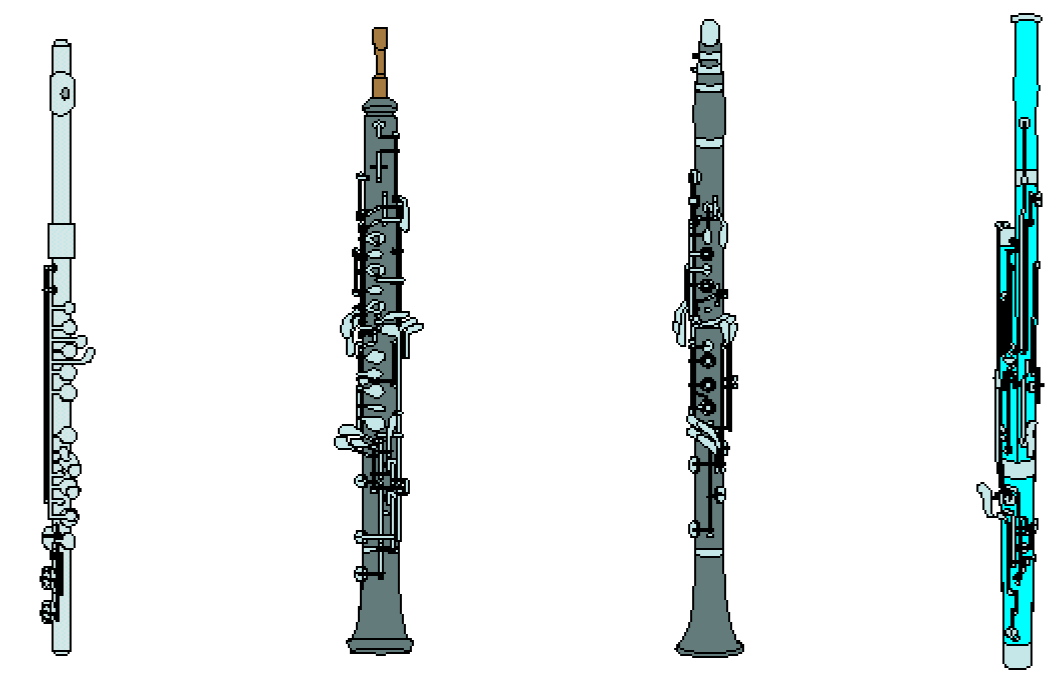


The Woodwind Choir

The "choir of woodwinds" is shown below. in Fig. W-10. Think of this analogy with a choir of singers: flute (soprano), oboe (alto), clarinet (tenor), and bassoon (bass).

Fig. W-10. Woodwind Ranges.





Flute (Fl) "Open Pipe"

Oboe (Ob) "Open Pipe"

Clarinet (Cl) "Closed Pipe"

Bassoon (Bn) "Open Pipe"

Not to scale.

The oboe and bassoon have double reeds. This makes each function more like an open pipe rather than a close pipe. Fill in the circle of the appropriate choice for each below.

Description	Flute	Clarinet	Oboe	Bassoon
Lowest Range	○	○	○	○
Closed Pipe	○	○	○	○
Double Reed Like the Bassoon	○	○	○	○
Single Reed	○	○	○	○
Can Reach the Highest Note	○	○	○	○
Range Closest to that of the Flute	○	○	○	○

--- End of Chapter W ---

