Sources of Musical Sound

I. Stringed Instruments

\( \lambda_n = \frac{2L}{n} \)

\( f_n = \frac{nV}{2L} \)

II. Wind Instruments

Antinodes (maximum oscillation) occur at the open ends.

Both ends open

\( f_n = \frac{nV}{2L} \quad n = 1, 2, 3 \)

One end open

\( f_n = \frac{nV}{4L} \quad n = 1, 3, 5 \)

Second

\( \lambda = \frac{2L}{2} = L \)

Third

\( \lambda = \frac{2L}{3} \)

Fourth

\( \lambda = \frac{2L}{4} = \frac{L}{2} \)

Two open ends—any harmonic

First

\( \lambda = \frac{4L}{1} \)

Second

\( \lambda = \frac{4L}{3} \)

Third

\( \lambda = \frac{4L}{5} \)

Fifth

\( \lambda = \frac{4L}{7} \)

Seventh

One open end—only odd harmonics
III. **Beating** = **Mixing** waves with different frequencies

\[ s_1 = s_m \cos \omega_1 t \]
\[ s_2 = s_m \cos \omega_2 t \]
\[ s' = s_1 + s_2 \]

\[
s' = s_m \cos \omega_1 t + s_m \cos \omega_2 t
   = s_m (\cos \omega_1 t + \cos \omega_2 t)
   \left[ \cos A + \cos B = 2 \cos \frac{A-B}{2} \cos \frac{A+B}{2} \right]
\]

\[
s' = 2s_m \cos \left( \frac{\omega_1 - \omega_2}{2} t \right) \cos \left( \frac{\omega_1 + \omega_2}{2} t \right)
   = \left[ 2s_m \cos \omega'_t \right] \cos \omega t
   \quad \omega' = \frac{1}{2} (\omega_1 - \omega_2)
   \quad \omega = \frac{1}{2} (\omega_1 + \omega_2)
\]

\[ \omega_{\text{beat}} = 2\omega' = \omega_1 - \omega_2 \]

\[ f_{\text{beat}} = f_1 - f_2 \]