Phase Difference
Distance between 2 points measured in degrees. 360° corresponds to 1 cycle

Path Difference
Distance between 2 points measured in fractions of the wavelength. \( \lambda \) corresponds to 1 cycle

Reflection:
Fixed End: reflected pulse is inverted. Phase changes by 180°
Open End: No inversion, no phase change.

Interference:
Two (or more) waves at the same point in space at the same moment in time interfere.
Constructive Interference

Phase Difference
0, 360°, 720° ...
\( n \times 360° \)

Path Difference
0, \( \lambda \), 2\( \lambda \), 3\( \lambda \)
\( n\lambda \)

Destructive Interference

Phase Difference
180°, 540° ...
\( (n + \frac{1}{2}) \times 360° \)

Path Difference
\( \frac{1}{2}\lambda \), 3/2 \( \lambda \), 5/2 \( \lambda \)
\( (n + \frac{1}{2})\lambda \)
Beats

Beats occur when two waves with similar frequencies interfere.

Beat frequency $f_B = f_2 - f_1$
**Standing Waves**: stable pattern caused by interference between a wave and its reflections

String, both ends fixed:

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>fundamental $\lambda_1 = 2L$</td>
<td>$f_1 = v/(2L)$</td>
</tr>
<tr>
<td>2nd harmonic $\lambda_2 = (2L)/2$</td>
<td>$f_2 = 2 v/(2L)$</td>
</tr>
<tr>
<td>3rd harmonic $\lambda_3 = (2L)/3$</td>
<td>$f_2 = 3 v/(2L)$</td>
</tr>
<tr>
<td>nth harmonic $\lambda_n = (2L)/n$</td>
<td>$f_n = n v/(2L)$</td>
</tr>
</tbody>
</table>
Longitudinal Standing Waves
Organ Pipes, Air Columns

Two open ends

\[ \lambda = 2L \]
\[ f = \frac{v}{2L} \]

\[ \lambda = 4L/2 \]
\[ f = 2 \cdot \frac{v}{4L} \]

\[ \lambda = 4L/3 \]
\[ f = 3 \cdot \frac{v}{4L} \]

One open, one closed end

\[ \lambda = 4L \]
\[ f = \frac{v}{4L} \]

\[ \lambda = 4L/3 \]
\[ f = 3 \cdot \frac{v}{4L} \]

\[ \lambda = 4L/5 \]
\[ f = 5 \cdot \frac{v}{4L} \]