# Combining Waves

- Traveling in same direction, same frequency:

$$y(x,t) = 2A\cos(\phi/2)\sin(kx - \omega t + \phi/2)$$

New amplitude

Phi is phase difference between orginals

- Opposite direction, same frequency (**standing wave**)

$$y(x,t) = 2A\sin(kx + \phi/2)\cos(\omega t + \phi/2)$$

# Boundary Conditions

- If medium is “stuck” on both ends they must be nodes of a standing wave
- Fundamental frequency/wavelength: exactly half a wave length fits between two ends
  - Harmonics: multiples of this
- Other boundary conditions are possible: open pipes are antinodes
  - Half open/half closed: odd multiples of quarter wavelengths allowed

# Doppler Effect

- Sound propagates relative to *air*
- Observed frequency changes if observer or source moving compared to air
- Source moving:

$$f' = \frac{f}{1 \pm u/v}$$

+: source moving away
-: source moving toward

- Observer moving: $f' = f(1 \pm u/v)$

+: observer moving toward
-: observer moving away