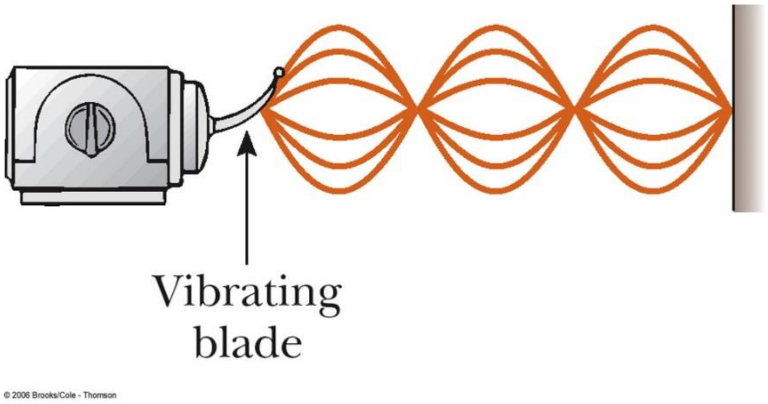
Standing Waves

- When a traveling wave reflects back on itself, it creates traveling waves in both directions
- The wave and its reflection interfere according to the superposition principle
- With exactly the right frequency, the wave will appear to stand still
  - This is called a *standing wave*

Standing Waves, cont

- A *node* occurs where the two traveling waves have the same magnitude of displacement, but the displacements are in opposite directions
  - Net displacement is zero at that point
  - The distance between two nodes is $\frac{1}{2}\lambda$
- An *antinode* occurs where the standing wave vibrates at maximum amplitude

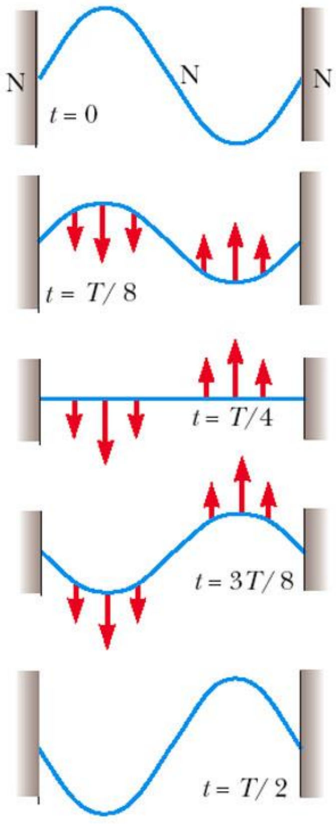
Standing Waves on a String



- Nodes must occur at the ends of the string because these points are fixed

Standing Waves, cont.

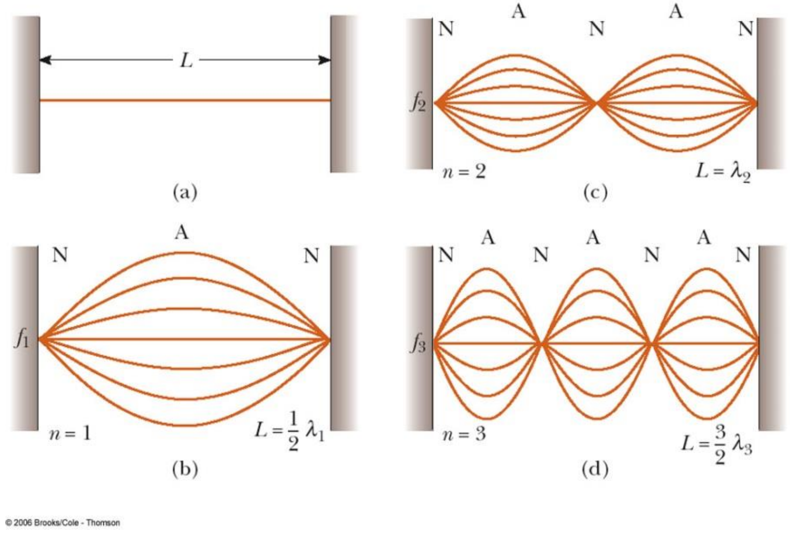
- The pink arrows indicate the direction of motion of the parts of the string
- All points on the string oscillate together vertically with the same frequency, but different points have different amplitudes of motion



Standing Waves on a String, final

- The lowest frequency of vibration (b) is called the *fundamental frequency*

$$f_n = nf_1 = \frac{n}{2L}\sqrt{\frac{F}{\mu}}$$



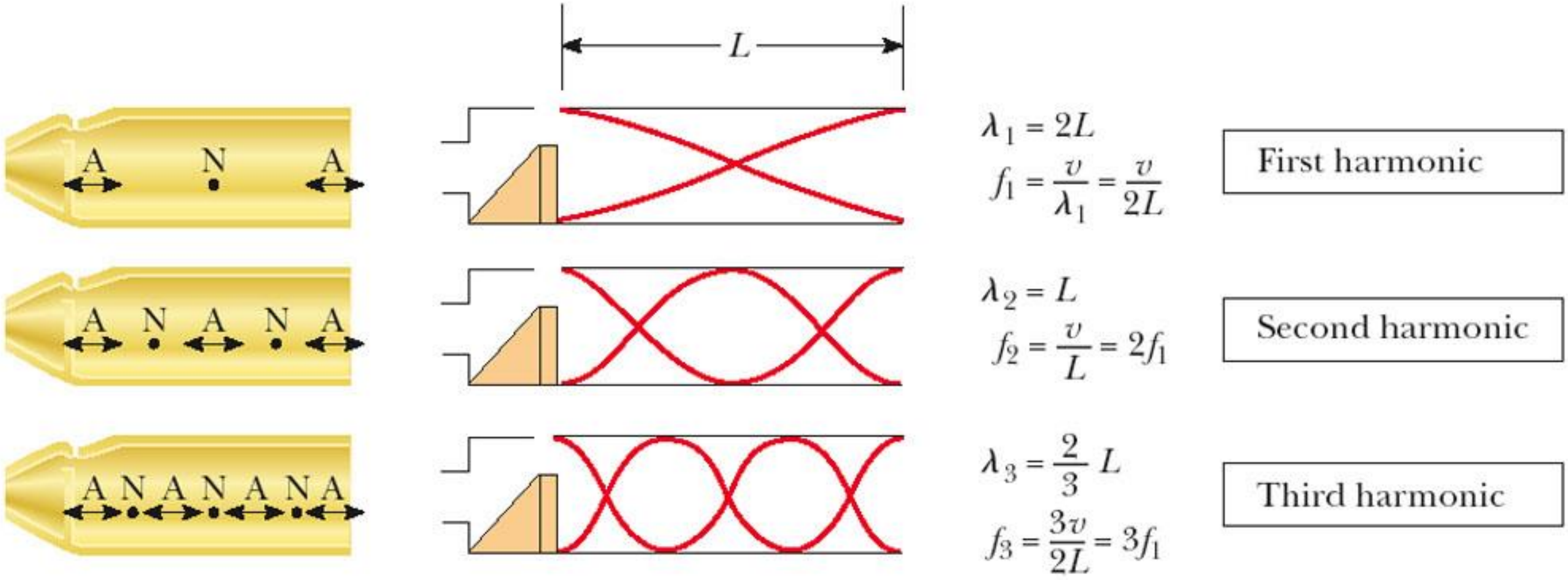
Standing Waves on a String – Frequencies

- f_1, f_2, f_3 form a harmonic series
  - f_1 is the fundamental and also the first harmonic
  - f_2 is the second harmonic
- Waves in the string that are not in the harmonic series are quickly damped out
  - In effect, when the string is disturbed, it "selects" the standing wave frequencies

Standing Waves in Air Columns

- If one end of the air column is closed, a node must exist at this end since the movement of the air is restricted
- If the end is open, the elements of the air have complete freedom of movement and an antinode exists

Tube Open at Both Ends



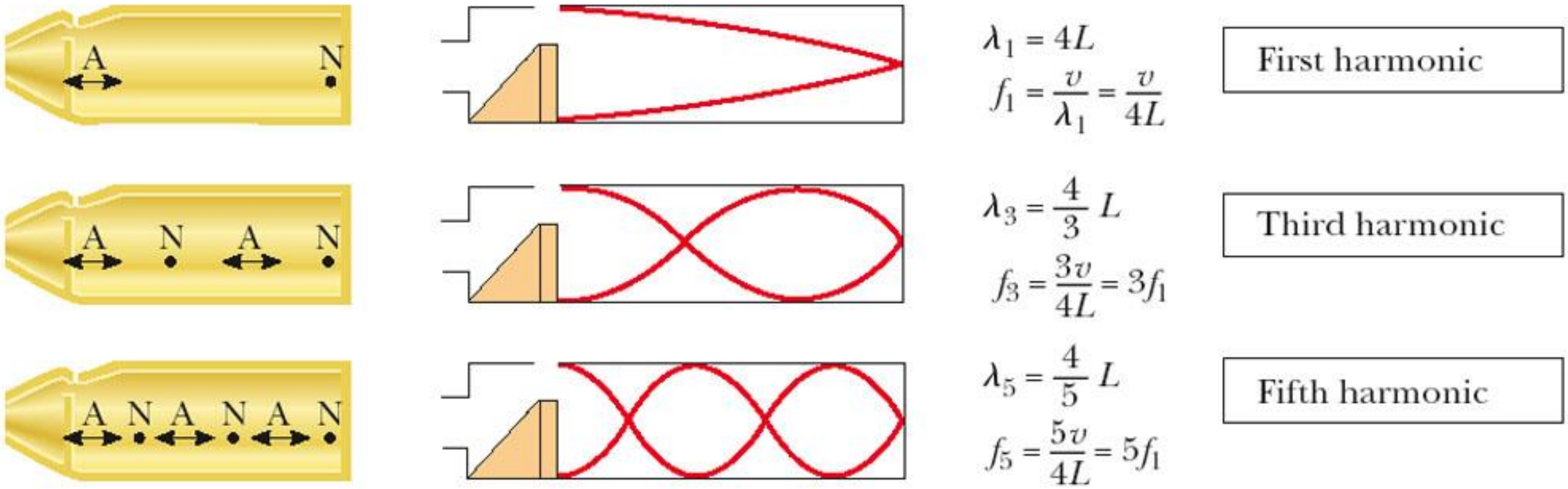
(a) Open at both ends

Resonance in Air Column Open at Both Ends

- In a pipe open at both ends, the natural frequency of vibration forms a series whose harmonics are equal to integral multiples of the fundamental frequency

$$f_n = n\frac{v}{2L} = nf_1 \quad n = 1, 2, 3, \ldots$$

Tube Closed at One End



(b) Closed at one end, open at the other

Resonance in an Air Column Closed at One End

- The closed end must be a node
- The open end is an antinode

$$f_n = n\frac{v}{4L} = nf_1 \qquad n = 1, 3, 5, \ldots$$

- There are no even multiples of the fundamental harmonic