# DEVIL PHYSICS
## THE BADDEST CLASS ON CAMPUS
## IB PHYSICS

# TSOKOS LESSON 4-6
# STANDING WAVES

# Essential Idea:

- When travelling waves meet they can superpose to form standing waves in which energy may not be transferred.

# Nature Of Science:

- *Common reasoning process:*
  - From the time of Pythagoras onwards the connections between the formation of standing waves on strings and in pipes have been modeled mathematically and linked to the observations of the oscillating systems. In the case of sound in air and light, the system can be visualized in order to recognize the underlying processes occurring in the standing waves.

# International-Mindedness:

- The art of music, which has its scientific basis in these ideas, is universal to all cultures, past and present. Many musical instruments rely heavily on the generation and manipulation of standing waves.

# Theory Of Knowledge:

- There are close links between standing waves in strings and Schrodinger's theory for the probability amplitude of electrons in the atom. Application to superstring theory requires standing wave patterns in 11 dimensions.
- What is the role of reason and imagination in enabling scientists to visualize scenarios that are beyond our physical capabilities?

# Understandings:

- The nature of standing waves
- Boundary conditions
- Nodes and antinodes

# Applications And Skills:

- Describing the nature and formation of standing waves in terms of superposition
- Distinguishing between standing and travelling waves
- Observing, sketching and interpreting standing wave patterns in strings and pipes
- Solving problems involving the frequency of a harmonic, length of the standing wave and the speed of the wave

# Guidance:

- Students will be expected to consider the formation of standing waves from the superposition of no more than two waves
- Boundary conditions for strings are: two fixed boundaries; fixed and free boundary; two free boundaries
- Boundary conditions for pipes are: two closed boundaries; closed and open boundary; two open boundaries

# Guidance:

- For standing waves in air, explanations will not be required in terms of pressure nodes and pressure antinodes
- The lowest frequency mode of a standing wave is known as the first harmonic
- The terms fundamental and overtone will not be used in examination questions

# Data Booklet Reference:

- ***None***

# Utilization:

- Students studying music should be encouraged to bring their own experiences of this art form to the physics classroom.

# Aims:

- Aim 3: students are able to both physically observe and qualitatively measure the locations of nodes and antinodes, following the investigative techniques of early scientists and musicians
- Aim 8: the international dimension of the application of standing waves is important in music

# Aims:

- Aim 6: experiments could include (but are not limited to): observation of standing wave patterns in physical objects (eg slinky springs); prediction of harmonic locations in an air tube in water; determining the frequency of tuning forks; observing or measuring vibrating violin/guitar strings

# Standing Waves – What It Isn't

# Introductory Video 1

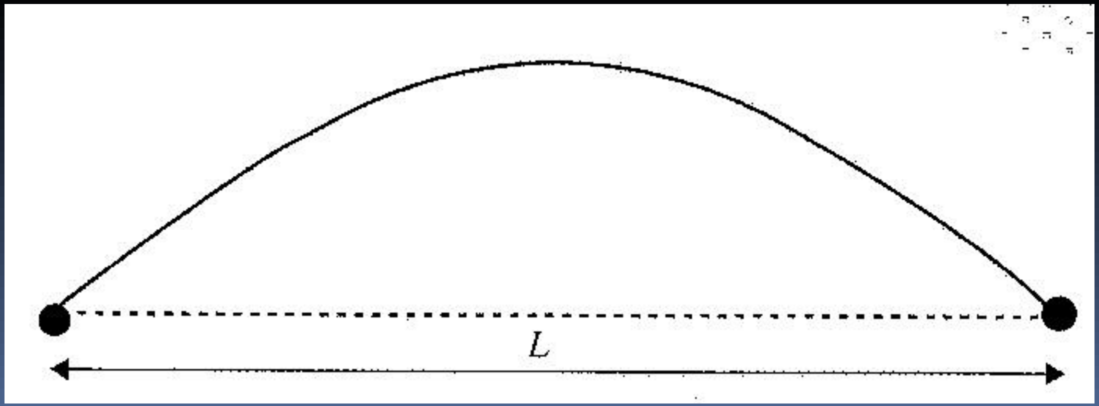
# Introductory Video 2

# Standing Waves on Strings

- *"When two waves of the same speed and wavelength and equal, or almost equal, amplitudes travelling in opposite directions meet, a standing wave is formed."*
- *"This wave is the result of the superposition of the two waves travelling in opposite directions."*

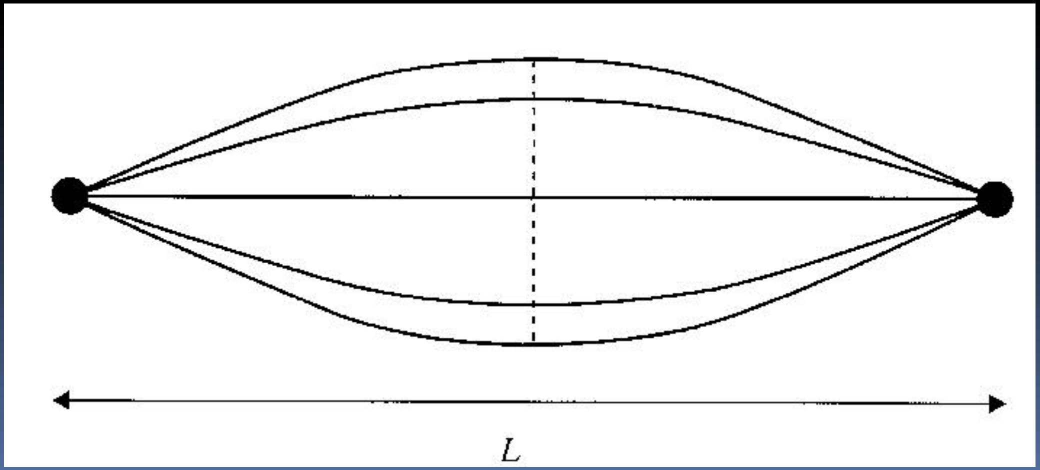
# Standing Waves on Strings

- Difference between standing and traveling waves
  - No energy or momentum is transferred in a standing wave
  - Standing wave has points where the displacement is ***always*** zero (***nodes***)
    - Points of maximum displacement are called ***antinodes***



# Standing Waves on Strings

- A standing wave with a single ***antinode*** is known as a ***fundamental standing wave***
- When the string is in the stretched position, all of its energy is potential energy
- When the string is in its unstretched position, all the energy is kinetic energy

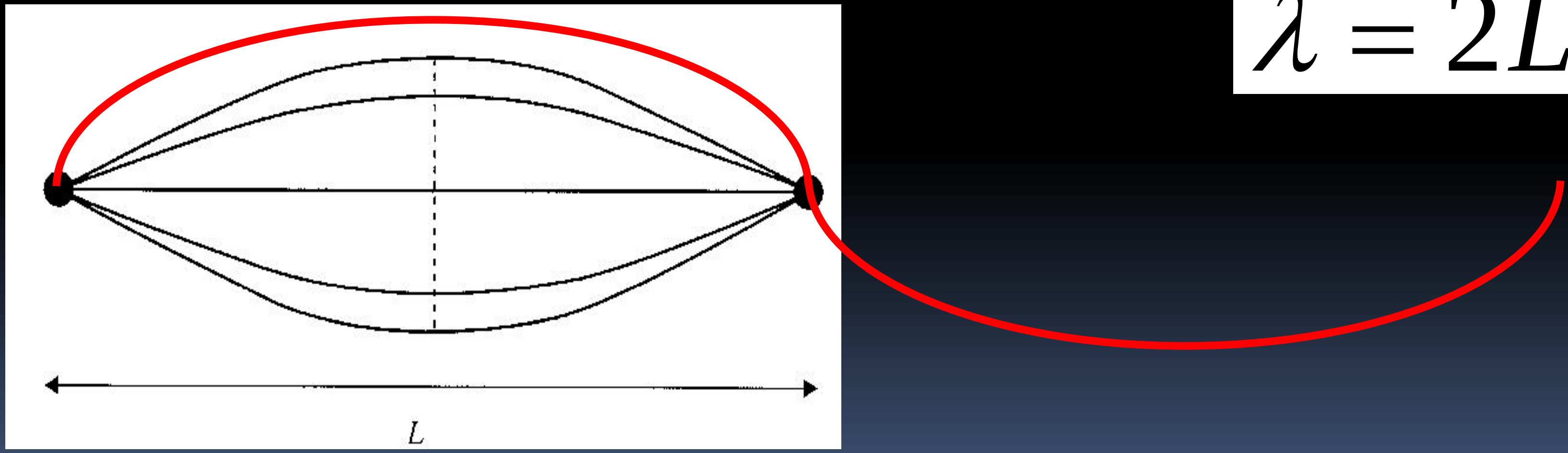


# Standing Waves on Strings

- In this picture, there is one-half of one wavelength depicted
- Therefore, the wavelength is:

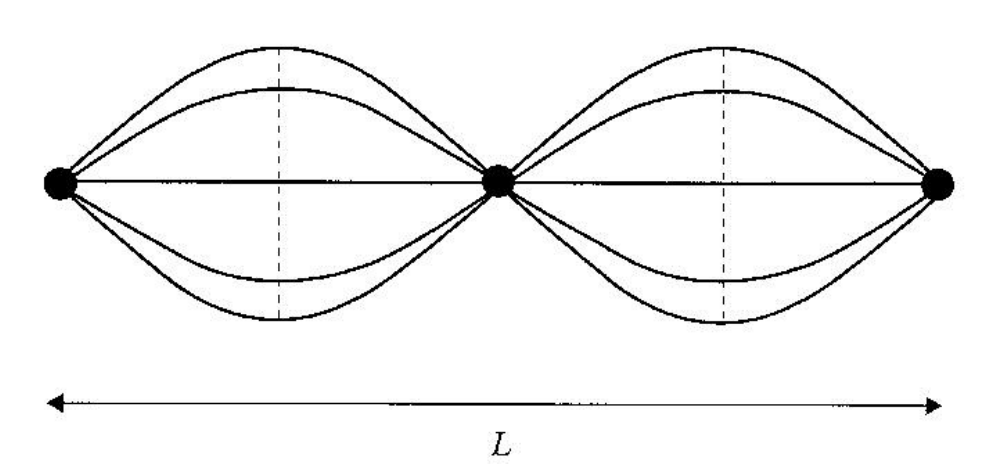
$$L = \frac{\lambda}{2}$$

$$\lambda = 2L$$



# Standing Waves on Strings

- This picture also depicts a standing wave, with one entire wavelength between the ends
- The string has three nodes and two antinodes
- The wavelength is:



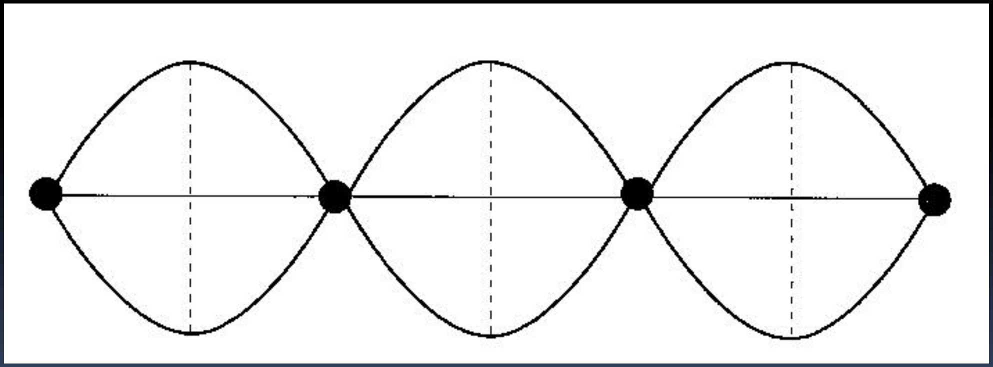

$$L = \lambda$$

# Standing Waves on Strings

- This standing wave has four nodes and three antinodes
- The wavelength is:

$$L = \frac{3}{2}\lambda$$

$$\lambda = \frac{2L}{3}$$



# Standing Waves on Strings

- A general formula for finding the wavelength of a string with both ends fixed is:

$$\lambda = \frac{2L}{n}$$

$$n = 1, 2, 3, 4, \ldots$$

- *n* is called the ***mode*** and n = 1 is call the ***fundamental mode*** or ***first harmonic*** of the string
- *n* also refers to the number of antinodes

# Standing Waves on Strings

- There is a frequency associated with the fundamental mode called, coincidentally, the ***fundamental frequency ($f_o$)***
- All other harmonics will have frequencies that are integral multiples of $f_o$

$$\lambda = \frac{2L}{n}$$

$$n = 1,2,3,4,\ldots$$

$$f_0 = \frac{v}{\lambda_1}$$

$$f_n = n\frac{v}{\lambda_1}$$

# Standing Waves on Strings

- Note that the smallest frequency is associated with the fundamental mode (largest wavelength)

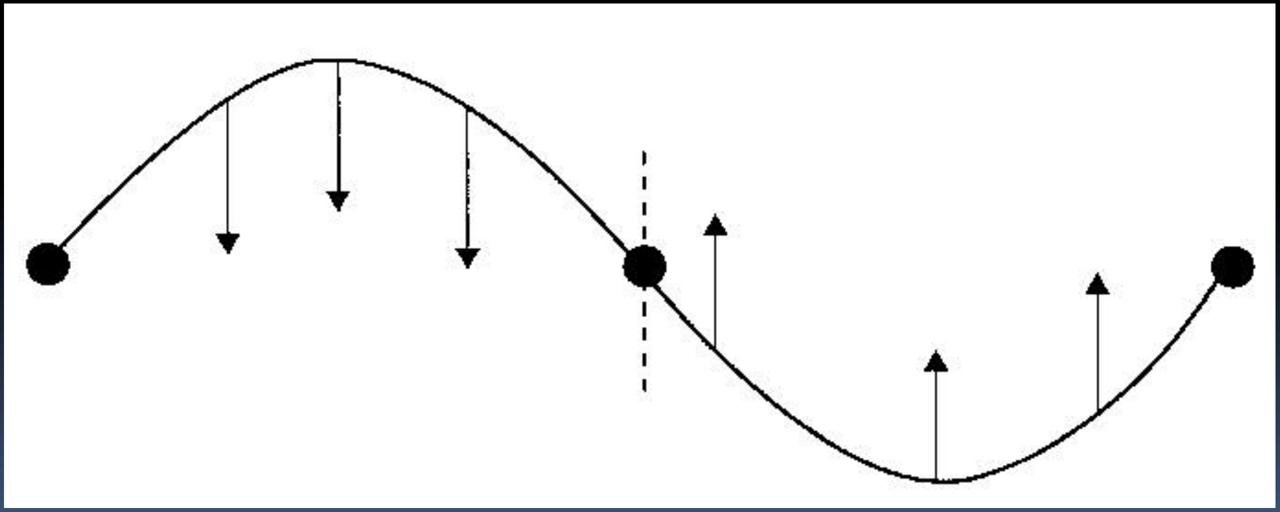
$$\lambda = \frac{2L}{n}$$

$$n = 1,2,3,4,\ldots$$

$$f = \frac{v}{\lambda}$$

# Standing Waves on Strings

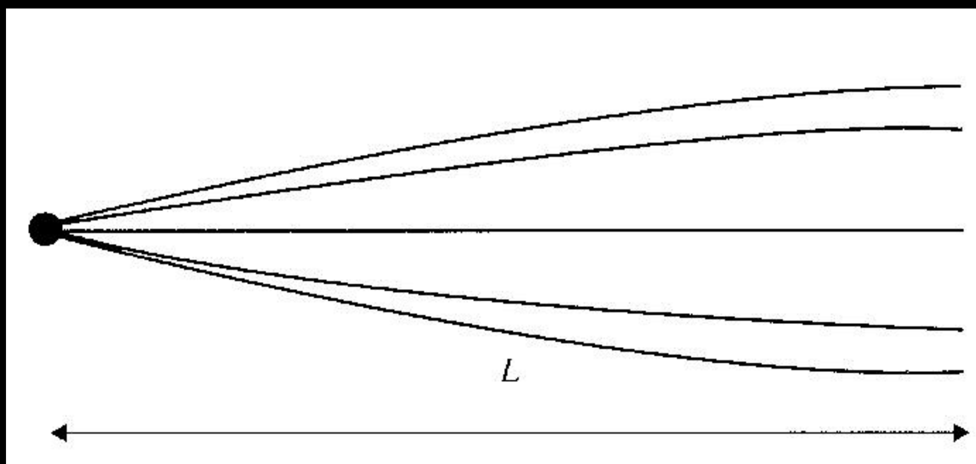
- All points between two consecutive nodes move in the same direction
- Particles between adjacent nodes move in the opposite direction



# Fun With PhET

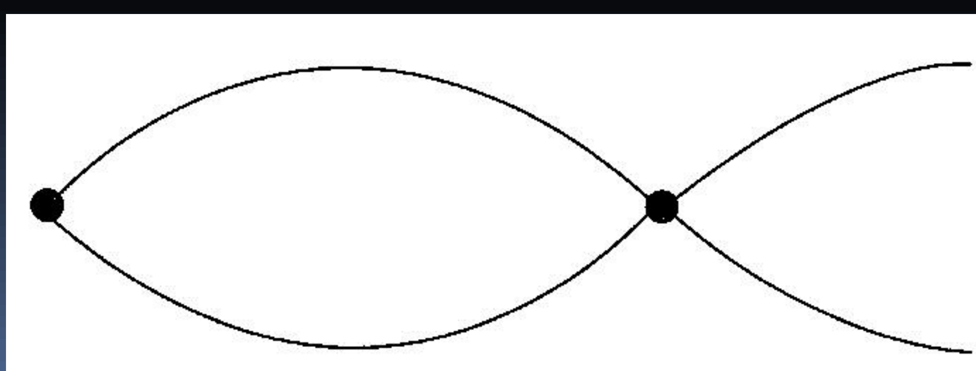
# Standing Waves on Strings

- String with one end fixed, one end free




$$L = \frac{1}{4}\lambda$$

$$\lambda = 4L$$

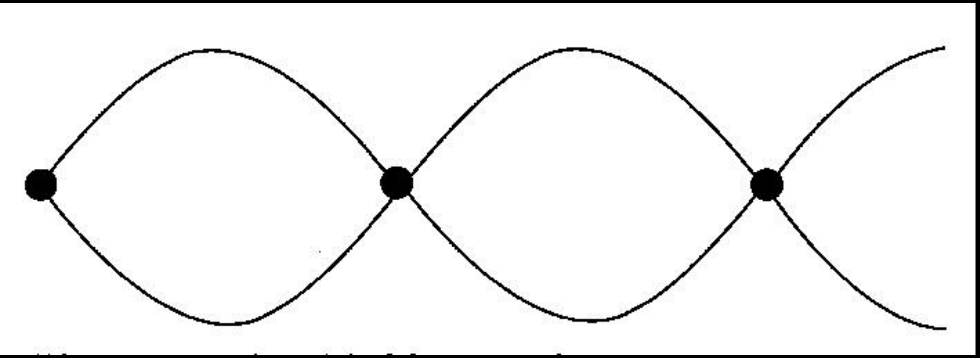


$$L = \frac{3}{4}\lambda$$

$$\lambda = \frac{4}{3}L$$

# Standing Waves on Strings

- String with one end fixed, one end free



$$L = \frac{5}{4}\lambda$$

$$\lambda = \frac{4}{5}L$$

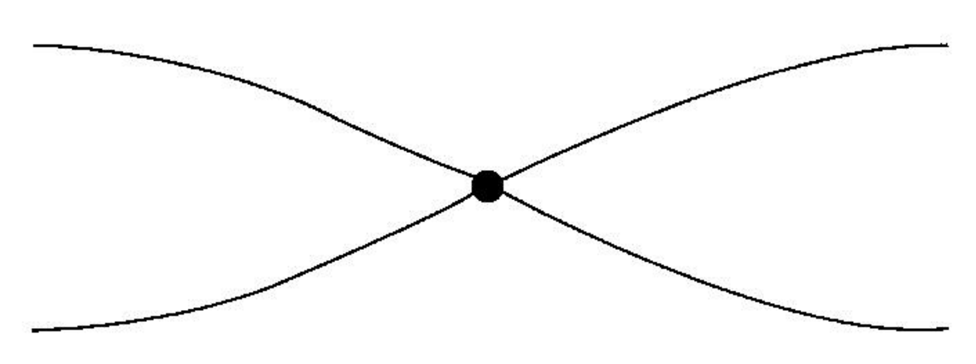
$$\lambda = \frac{4L}{n}$$

$$n = 1,3,5,7,\ldots$$

# Fun With PhET

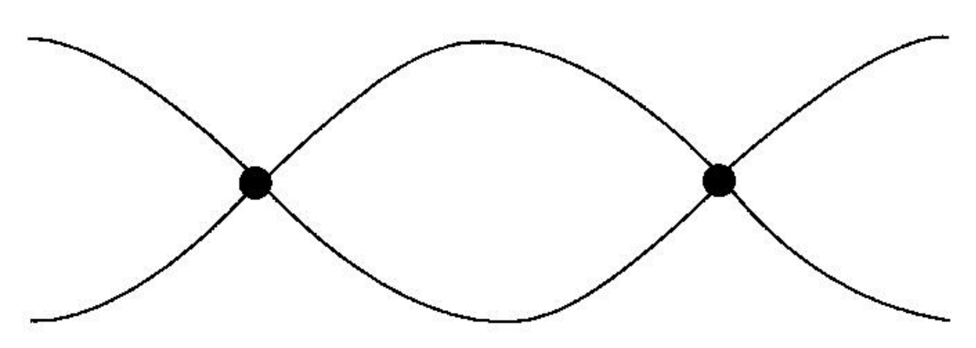
# Standing Waves on Strings

- String with both ends free



$$L = \frac{1}{2}\lambda$$

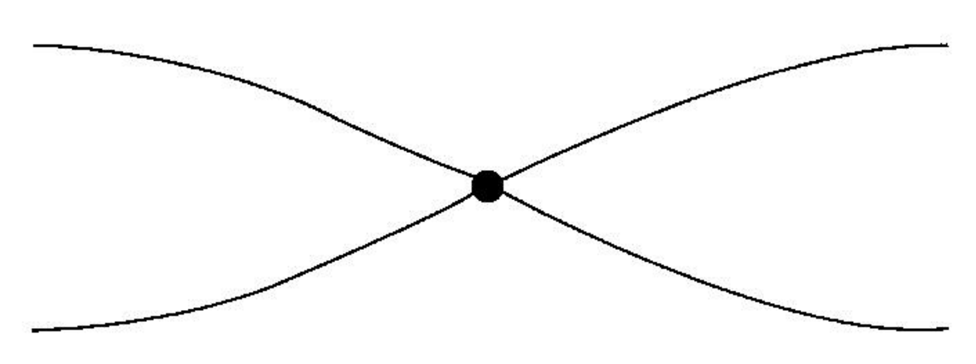
$$\lambda = 2L$$



$$L = \lambda$$

# Standing Waves on Strings

- String with both ends free, general formula



$$\lambda = \frac{2L}{n}$$

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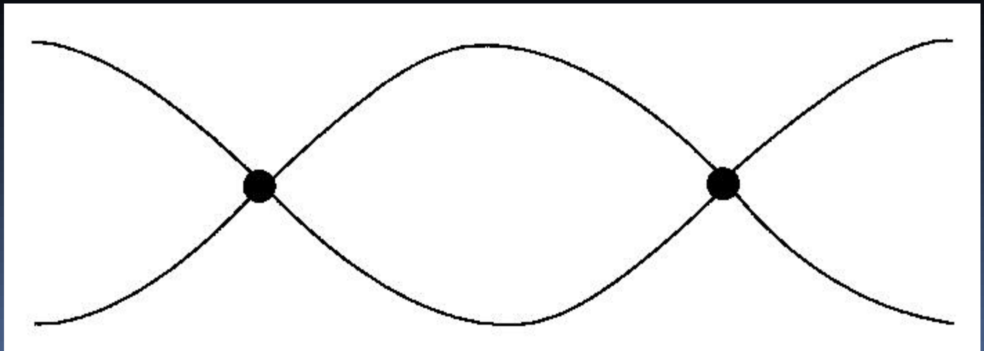
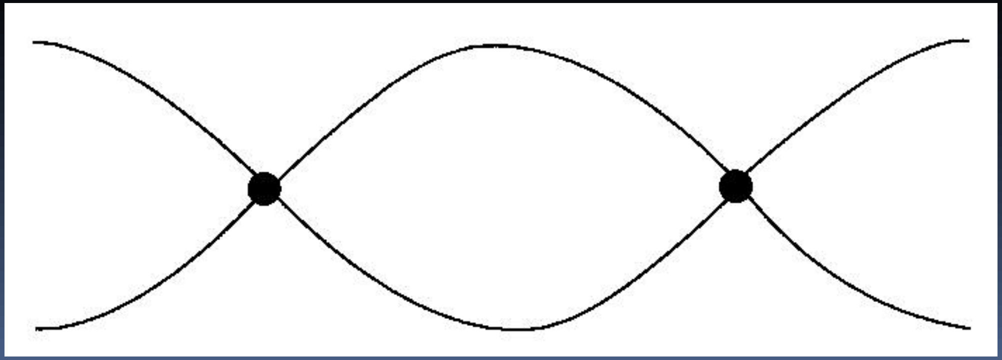


Same formula as that for two ends fixed.

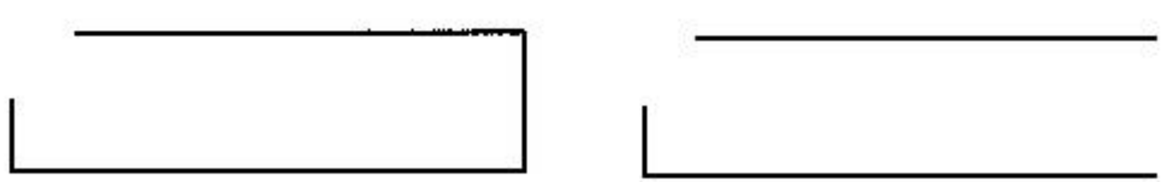
# Standing Waves on Strings

- No need to memorize formulas
- Distance between successive nodes or antinodes is a half wavelength
- Distance between a node and adjacent antinode is a quarter wavelength



# Standing Waves in Tubes

- Same as waves on a string
- Open end – string free - antinode
- Closed end – string fixed - node



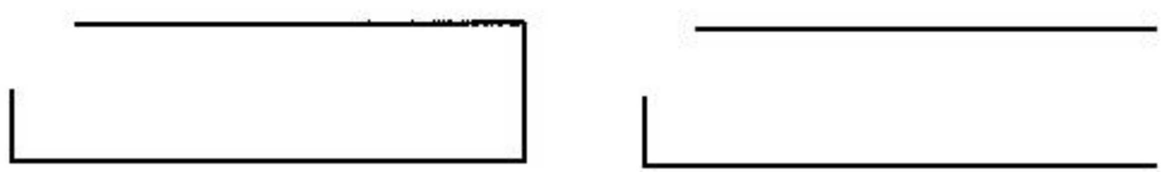
(a) left end (mouth) is open, right end is closed

(b) left end (mouth) is open, right end is open

# Standing Waves in Tubes

$$f = \frac{v}{\lambda}$$

- General Principle:
  - As the length of the tube gets smaller the wavelength for each harmonic gets smaller
  - Assuming constant wave speed (like sound), the smaller the wavelength, the higher the frequency
  - Think of the sound made when filling up a bottle of water



(a) left end (mouth) is open, right end is closed

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# QUESTIONS?

# Homework

#32-46