The Nature of Sound Waves

Read from **Lesson 1** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l1a.html
http://www.physicsclassroom.com/Class/sound/u11l1b.html
http://www.physicsclassroom.com/Class/sound/u11l1c.html

MOP Connection: Sound and Music: sublevel 1

TRUE or FALSE: Identify the following statements as being either true (T) or false (F).

T or F?

T 1. Sound waves are longitudinal waves.

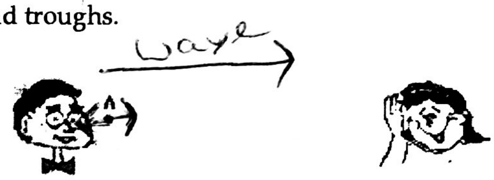
F 2. As the teacher talks, students hear the voice because particles of air move from the mouth of the teacher to the ear of the student.

T 3. Sound waves are mechanical waves.

T 4. All sound waves are produced by a vibrating object.

T 5. A sound wave does not consist of crests and troughs.

6. Mac is talking to Kate. The dot at A represents a particle of air. Describe the motion that this particle must undergo in order for Kate to hear Mac. Then show the motion by placing arrows on the diagram.

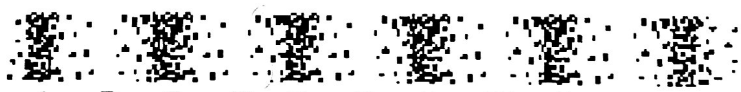


A must oscillate + bump the next particle to pass the wave along

7. Tosh is holding one end of a slinky; the opposite end is attached to a wall. Tosh wishes to produce a longitudinal wave in the slinky. Describe how Tosh must move his hand in order to produce a longitudinal wave. Then place arrows on the diagram to show the way in which Tosh must move his hand.

Like a "punch" in the direction of the wave

8. A sound wave is moving through air. The diagram below represents a snapshot of the air particles at a given instant in time. Several regions are labeled with a letter. Use the letters to identify the compressions and rarefactions.



A B C D E F G H I J K

Compressions: A C E G I K　　Rarefactions: B D F H J

9. A science fiction film depicts inhabitants of one spaceship (in outer space) hear the sound of a nearby spaceship as it zooms past at high speeds. Critique the physics of this film.

No particles in space to pass sound in

Properties of Sound Waves

Read from **Lesson 2** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l2a.html
http://www.physicsclassroom.com/Class/sound/u11l2b.html
http://www.physicsclassroom.com/Class/sound/u11l2c.html

MOP Connection: Sound and Music: sublevel 2

Review:
Match the following wave quantities to the *mini-definition*. Place the letter in the blank.

A. Frequency B. Period C. Speed D. Wavelength E. Amplitude

__C__ 1. **How fast** the wave moves through the medium.

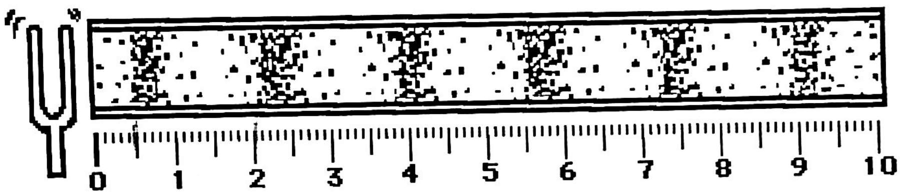
__D__ 2. **How long** the wave is.

__A__ 3. **How often** the particles vibrate about their fixed position.

__B__ 4. **How much time** it takes the particles to complete a vibrational cycle.

__E__ 5. **How far** the particles vibrate away from their resting position.

6. A sound wave with its characteristic pattern of compressions and rarefactions is shown below. A centimeter ruler is included below the pattern. The wavelength of this sound wave is __1.5__ cm.



7. The pitch of a sound is directly related to the __A__ of the sound wave.
a. frequency b. wavelength c. speed d. amplitude

8. High pitched sounds have relatively large __f__ and small __λ__.
a. period, wavelength
b. speed, period
c. frequency, wavelength
d. period, frequency
e. amplitude, wavelength
f. amplitude, speed

9. As the frequency of a sound increases, the wavelength _______ and the period _______.
a. increases, decreases
b. decreases, increases
c. increases, increases
d. decreases, decreases

10. A sound wave is described as being 384 waves/s. This quantity describes the wave's ________.
a. frequency b. period c. speed d. wavelength

11. The speed of a sound wave depends upon the __D__.
a. frequency of the wave
b. wavelength of the wave
c. amplitude of the wave
d. properties of the medium through which it moves

12. If a person yells (as opposed to whispering), then it will cause __C__.
a. air molecules to vibrate more frequently
b. the sound wave to travel faster
c. air molecules to vibrate with greater amplitude

13. If a person yells (as opposed to whispering), then it will cause __C__.
a. the pitch of the sound to be higher
b. the speed of the sound to be faster
c. the loudness of the sound to be louder

The Speed of Sound

Read from **Lesson 2** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l2c.html

1. When the C4 key on a piano keyboard is pressed, a string inside the piano is struck by a *hammer* and begins vibrating back and forth at approximately 260 cycles per second.
   a. What is the frequency in Hertz of the sound wave?

   260Hz

   b. Assuming the sound wave moves with a velocity of 345 m/s, what is the wavelength of the wave? **PSYW**

   $345 = 260 \cdot \lambda$

   1.33m

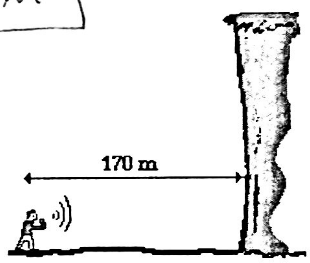
2. An automatic focus camera is able to focus on objects by use of an ultrasonic sound wave. The camera sends out sound waves that reflect off distant objects and return to the camera. A sensor detects the time it takes for the waves to return and then determines the distance an object is from the camera. If a sound wave (speed = 345 m/s) returns to the camera 0.115 seconds after leaving the camera, how far away is the object? **PSYW**

   $d = vt$

   $d = 345 \cdot 0.115 = 39.675$ m down + b

   distance away = 19.84m

3. Miles Tugo is camping in Glacier National Park. In the midst of a glacier canyon, he makes a loud holler. The sound (v = 345 m/s) bounces off the nearest canyon wall (which is located 170 meters away from Miles) and returns to Miles. Determine the time elapsed between when Miles makes the holler and the echo is heard. **PSYW**



   $d = vt$ $d = 170 \times 2$ ⇒ down + back

   $340 = 345 \cdot t$ $t = 0.99$ sec.

4. Suppose that sound travels at a speed of 345 m/s on the evening of a thunderstorm. There is a lightning strike some distance from your home. The light reaches you nearly immediately. Yet the thunder is heard 3.5 seconds later. How many miles from your home did the lightning strike? (1609 meters = 1 mile) **PSYW**

   $d = vt$

   $d = 345\frac{m}{s} \cdot 3.5s$ = 1207.5m

5. A male vocalist with a bass voice can sing as low as 85 Hz. Given that the speed of sound is 345 m/s, what is the wavelength of the sound waves? **PSYW**

   $v = \lambda \cdot f$

   $345 = \lambda \cdot 85$ $\lambda = 4.06$ m

6. A female vocalist with a soprano voice can sing as high as 1000 Hz. Given that the speed of sound is 345 m/s, what is the wavelength of the sound waves? **PSYW**

   $345 = 1000 \cdot \lambda$

   $\lambda = 0.345$m

The Doppler Effect

Read from **Lesson 3** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l3b.html

MOP Connection: Sound and Music: sublevel 4

1. **TRUE** or **FALSE:**

   Ken Fused is standing on a corner when a police car passes by with its siren on. Ken hears a different pitch when the police car is approaching him than when it is past him. This is because the siren on the front of the car is set to a higher pitch than the siren on the back of the car.

   False

2. Describe the real reason Ken Fused observes what he does.

   doppler effect - siren "catches up" to condensations & shortens wavelengths. Opposite when car retreats

3. **TRUE** or **FALSE:**

   The Doppler shift is a phenomenon that is observed only of sound waves.

   Explain your answer:

   False - can also be evidenced in light but only over huge distances/speeds

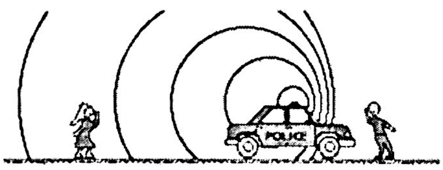
4. **TRUE** or **FALSE:**

   As the source of a sound approaches an observer, the loudness of the sound increases. This is an example of the Doppler Shift.

   Explain your answer:

   False - doppler effects frequency

An automobile is traveling away from Jill and towards Jack. The horn is *honking,* producing a sound wave consisting of the familiar pattern of alternating compressions and rarefactions which travel from their origin through the surrounding medium. The circles on the diagram at the right represent wave fronts; you can think of the wave fronts as the compressions. Observe that the compressions are closer together in front of the car compared to behind the car.



5. Towards which person do the sound waves travel the fastest?
   a. Jack b. Jill (c.) Both the same.
   ↳ set by medium

6. Who will hear the highest frequency?
   (a.) Jack b. Jill c. Both the same.

7. The Doppler effect can be described as the difference between the frequency at which sound waves are produced and the frequency at which they are observed by the hearer. It occurs when the distance between the source of a sound and the observer is changing. As the source approaches an observer, the observer hears the pitch (or frequency) to be __________ (higher, lower). As the source moves away from an observer, the observer hears the pitch (or frequency) to be __________ (higher, lower).

This is the BIG Idea

Resonance

Read from **Lesson 4** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l4a.html
http://www.physicsclassroom.com/Class/sound/u11l4b.html
http://www.physicsclassroom.com/Class/sound/u11l4c.html
http://www.physicsclassroom.com/Class/sound/u11l4d.html

MOP Connection: Sound and Music: sublevel 5

1. Define or describe the significance of the following terms:
   a. Natural frequency: frequency an object will vibrate at unrestrained or unforced
   b. Forced vibration: frequency an object is made to vibrate at
   c. Resonance: frequency where a standing wave is formed / constructive interference occurs

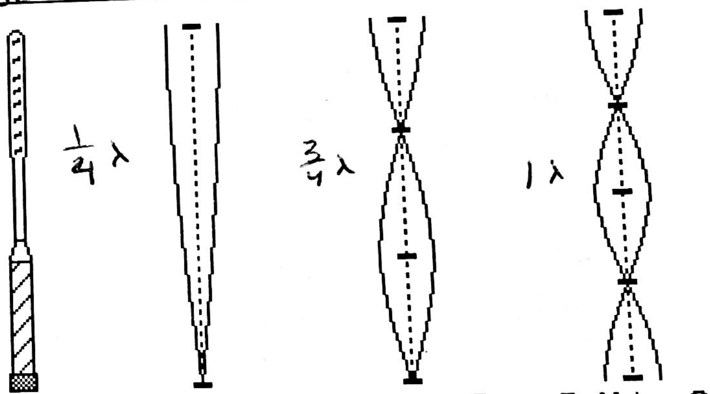
2. Three pairs of wooden dowel rods are mounted on a wooden platform. Small plastic cylinders are attached to their ends; the cylinders are colored red, green and blue. Each pair of dowel rods has a different length. One of the red cylinders is pulled back and let go of, causing it to begin vibrating back and forth with one complete cycle every two seconds. The natural frequency of this dowel rod is ______ Hz.

   $\frac{1 \text{ cycle}}{2 \text{ sec}} = 0.5 \text{ Hz}$

   a. 0.25 (b. 0.50) c. 1.0 d. 2.0

   As the red cylinder vibrates, it forces the other red cylinder to vibrate. This occurs because the two cylinders have the same natural frequency (color, composition, natural frequency). When two objects vibrate together like this resonance is occurring.

3. When a tennis racket strikes a tennis ball, the racket begins to vibrate. There is a set of selected frequencies at which the racket will tend to vibrate. Each frequency in the set is characterized by a particular standing wave pattern. The diagrams below show the three of the more common standing wave patterns for the vibrations of a tennis racket. In each diagram, hash marks are placed at the positions of all nodes and antinodes; label these nodes (N) and antinodes (AN).



Pattern A **Pattern B** **Pattern C**

Compare the wavelength of pattern A to the wavelength of pattern B. Make your comparison both qualitative and quantitative. Repeat for pattern C.

$\frac{1}{4}\lambda_A = \frac{3}{4}\lambda_B$ $\frac{1}{4}\lambda_A = 1\lambda$

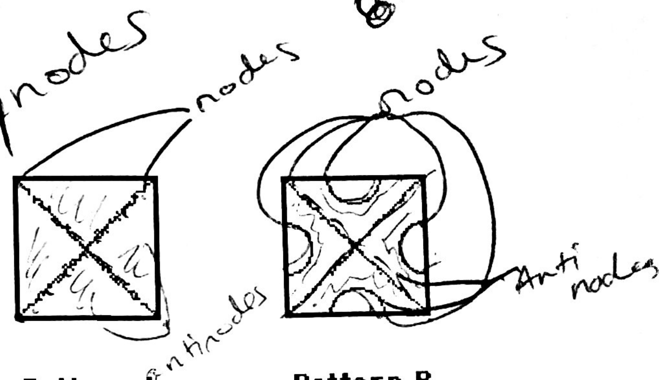
λ_A > λ_B (<, >, =) λ_A > λ_C (<, >, =)

λ_A = 3 • λ_B (2, 3, 4, etc.) λ_A = 4 • λ_C (2, 3, 4, etc.)

When the racket vibrates as in pattern A, its frequency of vibration is approximately 30 Hz. Determine the frequency of vibration of the racket when it vibrates as in pattern B and pattern C.

f_B = 90 Hz f_C = 120 Hz

4. In a rare moment of artistic brilliance, Mr. Henderson pulls out his violin bow and strokes a square metal plate to produce vibrations within the plate. Often times, he places salt upon the plates and observes the standing wave patterns established in the plate as it vibrates. Amazingly, the salt is aligned along the locations of the plate that are not vibrating and far from the locations of maximum vibration. The two most common standing wave patterns are illustrated at the right. Compare the wavelength of pattern A to the wavelength of pattern B. Place dots along the edge of the plates at all nodal (N) and antinodal (AN) positions; label these positions with an N and an AN.



When the plate vibrates as in pattern A, its frequency of vibration is nearly 4 000 Hz. Estimate the frequency of vibration of the plate when it vibrates as in pattern B. 8000 Hz

5. A guitar string has a set of natural frequencies at which it vibrates. Each frequency in the set is characterized by a standing wave pattern. The standing wave patterns for a guitar string are characterized by the presence of nodes at the end of the string (where it is clamped down). Each standing wave pattern (and its corresponding frequency) is called a *harmonic*. The first harmonic is the lowest frequency in the set (sometimes termed the *fundamental frequency*), followed by the second harmonic, third harmonic, etc. Draw the standing wave patterns for the first, second, and third harmonics of a guitar string.

1st Harmonic **2nd Harmonic** **3rd Harmonic**

Compare the wavelength of the 1st harmonic to the wavelengths of 2nd and 3rd harmonics.

λ_1 > λ_2 (<, >, =) λ_1 > λ_3 (<, >, =)

λ_1 = 2 • λ_2 (2, 3, 4, etc.) λ_1 = 3 • λ_3 (2, 3, 4, etc.)

Compare the frequency of the 1st harmonic to the frequencies of the 2nd and 3rd harmonics.

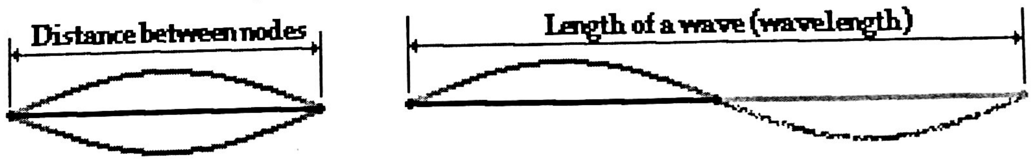
f_2 > f_1 (<, >, =) f_3 > f_1 (<, >, =)

f_2 = 2 • f_1 (2, 3, 4, etc.) f_3 = 3 • f_1 (2, 3, 4, etc.)

When the guitar string vibrates in the first harmonic ("fundamental frequency"), its frequency of vibration is approximately 200 Hz. Determine the frequency of second and third harmonics.

f_2 = 400 Hz f_3 = 600 Hz

6. Use the diagram below to compare the distance between two adjacent nodes on a standing wave pattern and the wavelength of a wave. Write a sentence comparing these two distances.



distance between nodes = 1/2 λ

Resonance and Guitar Strings

Read from **Lesson 5** of the **Sound and Music** chapter at **The Physics Classroom:**

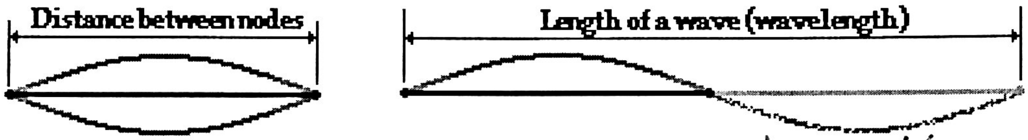
http://www.physicsclassroom.com/Class/sound/u11l5a.html
http://www.physicsclassroom.com/Class/sound/u11l5b.html

MOP Connection: Sound and Music: sublevels 6 and 7

Review

1. Standing wave patterns consist of nodes and antinodes. The positions along a medium that appear to be stationary are known as nodes. They are points of **no** displacement. The positions along a medium that are undergoing rapid motion between a maximum positive and maximum negative displacement are known as antinodes They are the **opposite of** the points of **no displacement**.

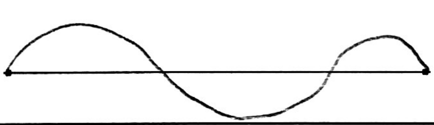
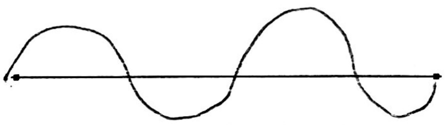
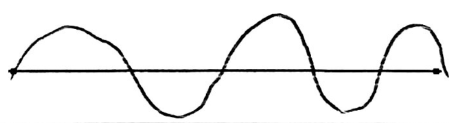
2. Use the diagram below to compare the distance between two adjacent nodes on a standing wave pattern and the wavelength of a wave. Write a sentence comparing these two distances.



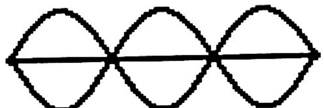
distance between nodes is $\frac{1}{2}$ a wavelength

Resonance in Strings:

3. Draw the standing wave patterns for the first five harmonics and complete the equations.

Harmonic #	Standing Wave Pattern	λ ---> L	L ---> λ
1		L = $\frac{1}{2}$ λ	λ = 2 L
2		L = 1 λ	λ = 1 L
3		L = $\frac{3}{2}$ λ	λ = $\frac{2}{3}$ L
4		L = 2 λ	λ = $\frac{1}{2}$ L
5		L = $\frac{5}{2}$ λ	λ = $\frac{2}{5}$ L

4. Determine the wavelength of the ...

a. ... wave in this 1.3-meter long string.  2 λ's = L = 1.3 m λ = 0.65 m	b. ... wave in this 85-cm long string.  1.5 λ's = L = 85 cm L = 56.67 cm
c. ... first harmonic wave pattern for a 78.5-cm long guitar string. λ = 157 cm ½ λ = 78.5 cm	d. ... fifth harmonic wave pattern for a 1.05-m long guitar string. 5/2 λ = 1.05 m λ = 0.42 m

Use the wave equation and your standing wave patterns to solve the following problems. **PSYW**

5. A guitar string with a length of 80.0 cm is plucked. The speed of a wave in the string is 400. m/sec. Calculate the frequency of the first harmonic. **PSYW**

$v = f \cdot \lambda$
$400 \frac{m}{s} = f \cdot 1.6 m$
$f = 250 Hz$

$L = \frac{1}{2} \lambda$
$0.8 m = \frac{1}{2} \lambda$
$\lambda = 1.6 m$

6. Calculate the frequency of the second and third harmonic for the string in question #5. **PSYW**

2nd → $400 \frac{m}{s} = 0.8 m \cdot f$
$L = 1 \lambda$
$.8 = \lambda$
$f = 500 Hz$

3rd → $0.8 = 1.5 \lambda$
$\lambda = .533 m$
$L = 1.5 \lambda$
$400 \frac{m}{s} = f \cdot 0.533 m$
$f = 750 Hz$

7. A pitch of Middle D (first harmonic = 294 Hz) is sounded out by a vibrating guitar string. The length of the string is 70.0 cm. Calculate the speed of the standing wave in the guitar string. **PSYW**

$L = 0.7 m = 0.5 \lambda$
$\lambda = 1.4 m$
$f = 294 Hz$
$v = \lambda \cdot f \rightarrow (1.4 m)(294 Hz) = 411.6 \frac{m}{s}$

8. A frequency of the first harmonic is 587 Hz (pitch of D5) is sounded out by a vibrating guitar string. The speed of the wave is 600. m/sec. Find the length of the string. **PSYW**

$L = \frac{1}{2} \lambda$
$v = f \cdot \lambda$
$600 \frac{m}{s} = 587 Hz \cdot \lambda$
$\lambda = 1.022 m$
$L = \frac{1}{2}(1.022 m)$
$L = 0.511 m$

9. A rope is vibrating in such a manner that three equal-length segments are found to be vibrating up and down with 321 complete cycles in 20.0 seconds. Waves travel at speeds of 26.4 m/s in the rope. What is the length of the rope? **PSYW**

$\frac{321 \text{ cycles}}{20 \text{ sec}} = 16.05 Hz$
$v = 26.4 \frac{m}{s} = f \cdot \lambda$
$26.4 \frac{m}{s} = 16.05 Hz \cdot \lambda$
$\lambda = 1.644$
$L = 1.5 \lambda$
$L = 1.5(1.644)$
$L = 2.47 m$

Resonance and Closed-End Air Columns

Read from **Lesson 5** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l5a.html
http://www.physicsclassroom.com/Class/sound/u11l5d.html

MOP Connection: Sound and Music: sublevels 10 and 11

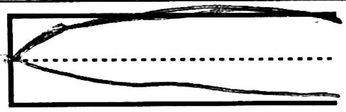
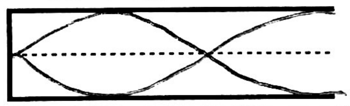
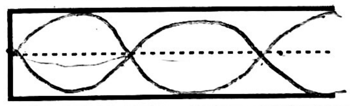
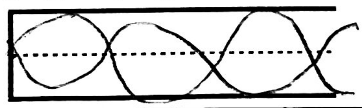
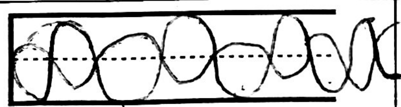
Review

1. Standing wave patterns consist of nodes and antinodes. The positions along a medium that appear to be stationary are known as ___nodes___. They are points of **no** displacement. The positions along a medium that are undergoing rapid motion between a maximum positive and maximum negative displacement are known as ___antinodes___. They are the **opposite of** the points of **no** displacement. Each consecutive node is separated from each other by ___1/2___ λ.

Resonance in Open-End Air Columns:

2. A closed-end air column is a column of air (usually enclosed within a tube, pipe or other narrow cylinder) that is capable of being forced into vibrational resonance. One end of the column is closed to the surrounding air and the other end is open to the surrounding air. Air at the open end of the column is able to vibrate back and forth; this end forms a vibrational ___anti-node___ (node, antinode). Air at the closed end is NOT able to vibrate back and forth; this end forms a vibrational ___node___ (node, antinode).

3. Draw the standing wave patterns for the first five harmonics and complete the equations.

Harmonic #	Standing Wave Pattern	λ ---> L	L ---> λ
1		L = 1/4 λ	λ = 4/1 L
3		L = 3/4 λ	λ = 4/3 L
5		L = 5/4 λ	λ = 4/5 L
7		L = 7/4 λ	λ = 4/7 L
9		L = 9/4 λ	λ = 4/9 L

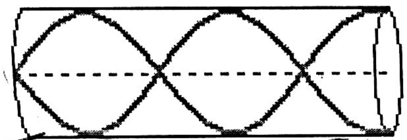
4. Determine the frequency of the .... → $\lambda_1 = 4L$ → divide by 3 multiply by 3
$\lambda_3 = 4/3\,L$ so f 3 multiply
   a. ... third harmonic for an air column whose first harmonic frequency is 262 Hz. ___786 Hz___
   b. ... first harmonic for an air column whose fifth harmonic frequency is 1700 Hz. ___340 Hz___ (→ divide by 5)
   c. ... fifth harmonic for an air column whose third harmonic frequency is 984 Hz. ___1640 Hz___
   d. ... next highest frequency for an air column whose fundamental frequency is 210 Hz. ___420 Hz___

→ divide by 3 multiply by 5
984 · 5/3

→ 1st Harmonic
next is 2nd Harmonic
so x 2

6. Determine the wavelength of the ...

a. ... wave in this 35-cm long air column.

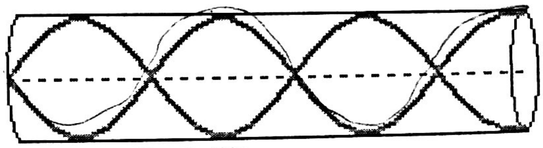


$L = 1.25\lambda$

$35 = 1.25\lambda$

$\lambda = 28$ cm

b. ... wave in this 56-cm long air column.



$L = 3.25\lambda$

$56 = 3.25\lambda$

$\lambda = 17.23$ cm

c. ... first harmonic wave pattern for a 32-cm long air column (closed).

$L = \frac{1}{4}\lambda$ $\quad 32 = \frac{1}{4}\lambda$

$\lambda = 128$ cm

d. ... fifth harmonic wave pattern for a 1.20-meter long air column (closed).

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

$\lambda = \frac{4}{5}(1.2)$

$\lambda = 0.96$ m

7. *The Test Tubes* have a *gig* in the local park this weekend. The lead instrumentalist uses a test tube (closed end air column) with a 17.2 cm air column. The speed of sound in the test tube is 340 m/sec. Find the frequency of the first harmonic played by this instrument. **PSYW**

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

$17.2\text{ cm} = \frac{1}{4}\lambda$

$\lambda = 68.8$ cm

$V = \lambda \cdot f$

$340 \frac{m}{s} = 68.8\text{ m} \cdot f$

$f = 494.19$ Hz

8. A closed end organ pipe is used to produce a mixture of sounds. The third and fifth harmonics in the mixture have frequencies of 1100 Hz and 1833 Hz respectively. What is the frequency of the first harmonic played by the organ pipe? **PSYW**

$\frac{1100}{3} = \frac{1833}{5} = \frac{f_1}{1}$

$f_1 = 366.6$ Hz

9. *Pipin' Pete and the Pop Bottles* is playing at Shades next weekend. One of the pop bottles is capable of sounding out a first harmonic of 349.2 Hz. The speed of sound is 345 m/sec. Find the length of the air column. **PSYW**

$345 = 349.2 \cdot \lambda$

$\lambda = 0.99$ m $\quad L = \frac{1}{4}\lambda$

$L = 0.248$ m

10. The sound produced by blowing over the top of a partially filled soda pop bottle is the result of the closed-end air column inside of the bottle vibrating at its natural frequency. Keri Atune uses four bottles (labeled A, B, C and D) with varying amounts of water (and thus, air) in order to play a song. Express your understanding of closed-end resonance by filling in the table below. (The speed of sound in the air columns is 345 m/s.)

Bottle	Length of Column (m)	Wavelength (m)	Frequency (Hz)	Speed (m/s)
A	0.060	$L = \frac{1}{4}\lambda$ = 0.24 m	1437.5	345
B	$L = \frac{1}{4}\lambda$ = 0.1225 m	0.49 m	708	345
C	$L = \frac{1}{4}\lambda$ = 0.16 m	0.640	539.063 Hz	345
D	0.200	$L = \frac{1}{4}\lambda$ = 0.8 m	431.25 Hz	345

$345 = 0.24 \cdot f$

$345 = 708 \cdot \lambda$

$345 = 0.64 \cdot f$

Name: ____________________

Resonance and Open-End Air Columns

Read from **Lesson 5** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l5a.html
http://www.physicsclassroom.com/Class/sound/u11l5c.html

MOP Connection: Sound and Music: sublevels 8 and 9

Review

1. Standing wave patterns consist of nodes and antinodes. The positions along a medium that appear to be stationary are known as nodes. They are points of **no displacement**. The positions along a medium which are undergoing rapid motion between a maximum positive and maximum negative displacement are known as anti-nodes. They are the **opposite of** the points of **no displacement**. Each consecutive node is separated from each other by 1/2 λ.

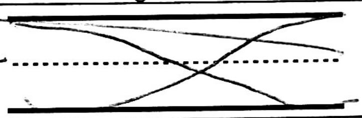
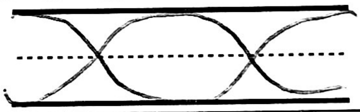
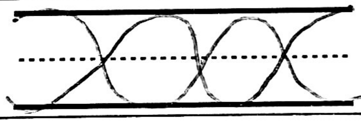
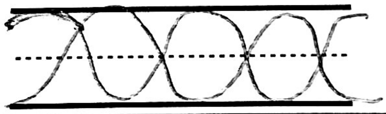
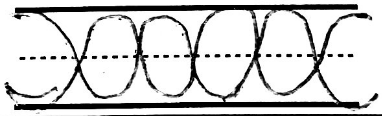
2. Define fundamental frequency:
   first frequency where a standing wave is formed

Resonance in Open-End Air Columns:

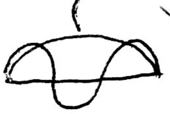
3. An open-end air column is a column of air (usually enclosed within a tube, pipe or other narrow cylinder) that is capable of being forced into vibrational resonance. Both ends of the column are open to the surrounding air. Air at the ends of the column is able to vibrate back and forth. Thus, these ends form vibrational ________________ (nodes, antinodes).

4. Draw the standing wave patterns for the first five harmonics and complete the equations.

anti-nodes on end

Harmonic #	Standing Wave Pattern	λ ---> L	L ---> λ
1		L = 1/2 λ	λ = 2 L
2		L = 1 λ	λ = 1 L
3		L = 3/2 λ	λ = 2/3 L
4		L = 2 λ	λ = 1/2 L
5		L = 5/2 λ	λ = 2/5 L

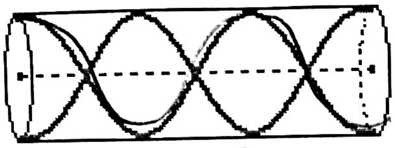
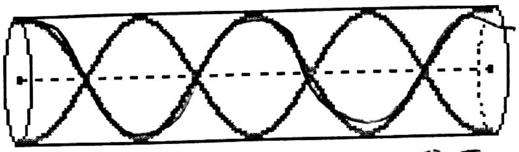
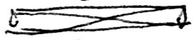
1st λ₁ = 2L, λ₃ = 2/3



5. Determine the frequency of the ....
   a. ... third harmonic for an air column whose first harmonic frequency is 384 Hz. 1152
   b. ... first harmonic for an air column whose fourth harmonic frequency is 1296 Hz. 324 Hz
   c. ... third harmonic for an air column whose fourth harmonic frequency is 528 Hz. 396 Hz

So λ₃ = divided by 3, inverse of freq, so f₃ = multiply by 3

6. Determine the wavelength of the ...

a. ... wave in this 63-cm long air column.  $1.5\lambda = L = 63\text{ cm}$ $\lambda = 42\text{ cm}$	b. ... wave in this 85-cm long air column.  $2\lambda = L = 85\text{ cm}$ $\lambda = 42.5\text{ cm}$
c. ... first harmonic wave pattern for a 42.5-cm long air column.  $\frac{1}{2}\lambda = L$ $\frac{1}{2}\lambda = 42.5\text{ cm}$ $\lambda = 85\text{ cm}$	d. ... fifth harmonic wave pattern for a 1.40-m long air column.  $2.5\lambda = 1.4$ $\lambda = 0.56\text{ m}$

Use the wave equation and your standing wave patterns to solve the following problems. **PSYW**

7. Stan Dinghwaives is playing his open end pipe. The frequency of the second harmonic is 882 Hz (a pitch of A5). The speed of sound through the pipe is 345 m/sec. Find the frequency of the first harmonic and the length of the pipe. **PSYW**

$f_2 = f_1 \cdot 2$

$882 = f_1 \cdot 2$

$f_1 = 441\text{ Hz}$

$V = \lambda \cdot f$

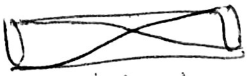
$345\frac{m}{s} = \lambda \cdot 882\text{ Hz}$

$\lambda = 0.39\text{ m}$

$\lambda = L$

$L = 0.39\text{ m}$

8. A flute is played with a first harmonic of 196 Hz (a pitch of G3). The length of the open-end air column is 89.2 cm (quite a long flute). Find the speed of the wave resonating in the flute. **PSYW**



$f_1 = 196\text{ Hz}$

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

$L = 89.2\text{ cm} = \frac{1}{2}\lambda \rightarrow \lambda = 178.4\text{ m}$

$V = \lambda \cdot f$

$V = (178.4\text{ m})(196\text{ Hz}) = 349.66\frac{m}{s}$

9. Find the length of a flute that would resonate at 262 Hz on a day when the speed of sound in air is 345 m/s. **PSYW** $V = 345\frac{m}{s}$ $f = 262\text{ Hz}$ → Let's shoot for 1st harmonic

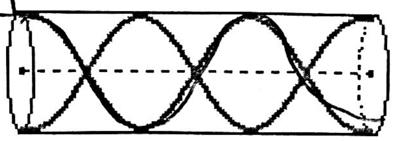
$V = \lambda \cdot f = \lambda \cdot 262$

$\lambda = 1.32\text{ m}$

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

$L = \frac{1}{2}(1.36\text{ m}) = 0.66\text{ m}$

10. Find the frequency of a 63.8-cm long open end air column that resonates as shown in the diagram at the right. The speed of sound in the air is 345 m/s.



$V = 345\frac{m}{s}$ $L = 63.8\text{ cm}$

$L = 1.5\lambda$

$63.8\text{ cm} = 1.5\lambda$

$\lambda = 0.425\text{ m}$

$345\frac{m}{s} = f \cdot (0.425\text{ m})$

$f = 811.76\text{ Hz}$

Sound and Music **Name:** ____________________

Resonance and Closed-End Air Columns

Read from **Lesson 5** of the **Sound and Music** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/sound/u11l5a.html
http://www.physicsclassroom.com/Class/sound/u11l5d.html

MOP Connection: Sound and Music: sublevels 10 and 11

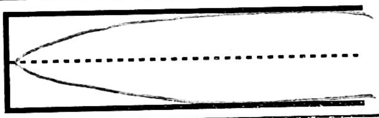
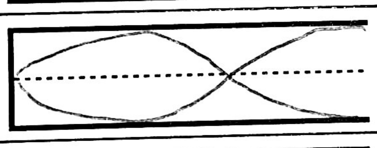
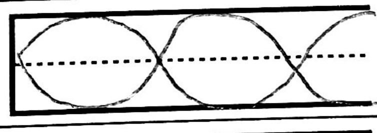
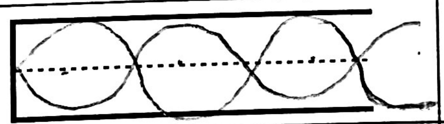
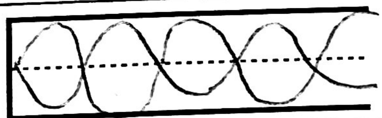
Review

1. Standing wave patterns consist of nodes and antinodes. The positions along a medium that appear to be stationary are known as nodes. They are points of **no** displacement. The positions along a medium that are undergoing rapid motion between a maximum positive and maximum negative displacement are known as antinodes. They are the **opposite of** the points of **no** displacement. Each consecutive node is separated from each other by 1/2 λ.

Resonance in Open-End Air Columns:

2. A closed-end air column is a column of air (usually enclosed within a tube, pipe or other narrow cylinder) that is capable of being forced into vibrational resonance. One end of the column is closed to the surrounding air and the other end is open to the surrounding air. Air at the open end of the column is able to vibrate back and forth; this end forms a vibrational antinodes (node, antinode). Air at the closed end is NOT able to vibrate back and forth; this end forms a vibrational node (node, antinode).

3. Draw the standing wave patterns for the first five harmonics and complete the equations.

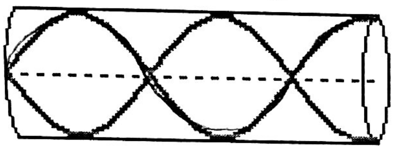
Harmonic #	Standing Wave Pattern	λ ---> L	L ---> λ
1		L = 1/4 λ	λ = 4 L
3		L = 3/4 λ	λ = 4/3 L
5		L = 5/4 λ	λ = 4/5 L
7		L = 7/4 λ	λ = 4/7 L
9		L = 9/4 λ	λ = 4/9 L

4. Determine the frequency of the .... ↗ $\lambda_1 = 4L$, $\lambda_3 = 4/3\,L$ ↗ λ is 1/3 so f 3 × 3
   a. ... third harmonic for an air column whose first harmonic frequency is 262 Hz. 786 Hz
   b. ... first harmonic for an air column whose fifth harmonic frequency is 1700 Hz. 340 Hz
   ↳ divide by 5
   c. ... fifth harmonic for an air column whose third harmonic frequency is 984 Hz. 1640 Hz
   ↳ divide by 3 multiply by 5
   d. ... next highest frequency for an air column whose fundamental frequency is 210 Hz. 420 Hz

↳ 1st harmonic to 2nd harmonic
so × 2

6. Determine the wavelength of the ...

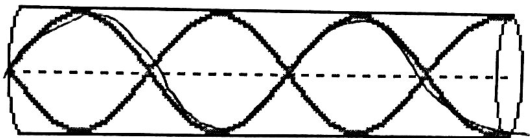
a. ... wave in this 35-cm long air column.



$L = 1.25\lambda$

$35 cm = 1.25\lambda$ $\lambda = 28 cm$

b. ... wave in this 56-cm long air column.



$L = 1.75\lambda$

$56 cm = 1.75\lambda$ $\lambda = 32 cm$

c. ... first harmonic wave pattern for a 32-cm long air column (closed).

$32 = \frac{1}{4}\lambda$

$L = \frac{1}{4}\lambda$ $\lambda = 128 cm$

d. ... fifth harmonic wave pattern for a 1.20-meter long air column (closed).

$L = \frac{5}{4}\lambda$ $1.2 = \frac{5}{4}\lambda$ $\lambda = 0.96 m$

7. *The Test Tubes* have a *gig* in the local park this weekend. The lead instrumentalist uses a test tube (closed end air column) with a 17.2 cm air column. The speed of sound in the test tube is 340 m/sec. Find the frequency of the first harmonic played by this instrument. **PSYW**

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

$0.172 m = \frac{1}{4}\lambda$

$\lambda = 0.688 m$

$v = f \cdot \lambda = 340 \frac{m}{s}$

$340 \frac{m}{s} = f \cdot 0.688 m$

$f = 494.19 Hz$

8. A closed end organ pipe is used to produce a mixture of sounds. The third and fifth harmonics in the mixture have frequencies of 1100 Hz and 1833 Hz respectively. What is the frequency of the first harmonic played by the organ pipe? **PSYW** $\frac{1100 Hz}{3} = \frac{1833 Hz}{5} = f_1 = 366.6 Hz$

9. *Pipin' Pete and the Pop Bottles* is playing at Shades next weekend. One of the pop bottles is capable of sounding out a first harmonic of 349.2 Hz. The speed of sound is 345 m/sec. Find the length of the air column. **PSYW** $f_1 = 349.2 Hz$ $v = 345 m/s$

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

$v = f \cdot \lambda$

$\lambda = 0.99 m = 4L$ $L = 0.2475 m$

10. The sound produced by blowing over the top of a partially filled soda pop bottle is the result of the closed-end air column inside of the bottle vibrating at its natural frequency. Keri Atune uses four bottles (labeled A, B, C and D) with varying amounts of water (and thus, air) in order to play a song. Express your understanding of closed-end resonance by filling in the table below. (The speed of sound in the air columns is 345 m/s.)

Bottle	Length of Column (m)	Wavelength (m)	Frequency (Hz)	Speed (m/s)
A	0.060	0.24 m	1437.5 Hz	345
B	0.1225 m	0.49 m	708	345
C	0.16 m	0.640	539.063 Hz	345
D	0.200	0.8 m	431.25 Hz	345

@ fundamental frequency, $L = \frac{1}{4}\lambda$

$v = \lambda \cdot f$