PHYSICS 2204
Unit 4: Waves
Worksheet #7: Resonance of Sound

Student Name: ____________________________

Many musical instruments depend on the musician in some way moving air through the instrument.

•This includes brass and woodwind instruments, as well as instruments like pipe organs.

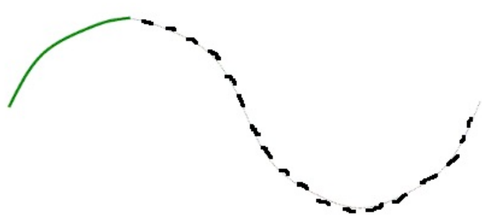
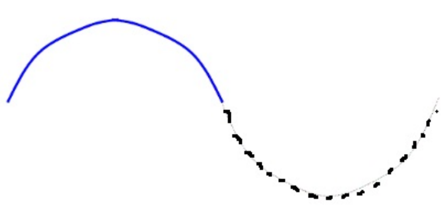
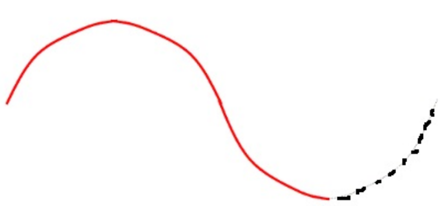
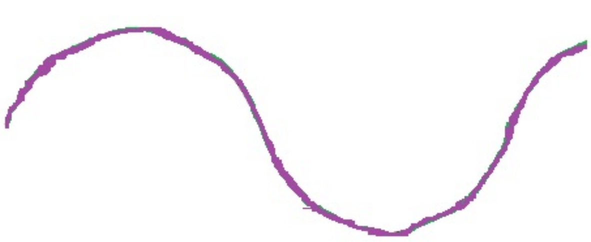
• An "**air column**" as the air contained inside a tube or pipe. Air columns can be divided into two categories, **open ended** or **closed ended**.

The frequencies of sounds made by these two types of instruments are different because of the different ways that air will move at a closed or open end of the column.

•The diagrams that I will be drawing are based on the way the air will move as a wave.

•Although the sound waves actually travel through the columns s as longitudinal waves, I will be drawing transverse waves. This is just because they are easier to draw and recognize in the diagrams.

Identifying Fractions of Wavelengths

	$\frac{1}{4}\lambda$
	$\frac{1}{2}\lambda$
	$\frac{3}{4}\lambda$
	λ
	$\frac{5}{4}\lambda$

These wave fractions might appear upside down, flipped over, turned around, etc., but they will still represent portions of a wave.

- When we are talking about the sounds that pipes can make, what we are really concerned with is how much of the wave we can fit into the pipe.

- Different amounts of a wavelength in an air column will result in a different frequency being heard.

- Because these are the frequencies of the waves that will naturally resonate in the air colums, we call them the resonant frequencies.

- In music, you might have heard these referred to as **harmonics.**

Although the actual length of the pipe remains the same, different notes are played

- If you have ever played a wind instrument, you know that with the same keys pressed you can play different notes by controlling how you blow into the instrument… the difference between let's say a low C and a high C note.

- The lowest note you can play (which is also the smallest part of the wave that can fit inside the pipe) is usually called the fundamental.

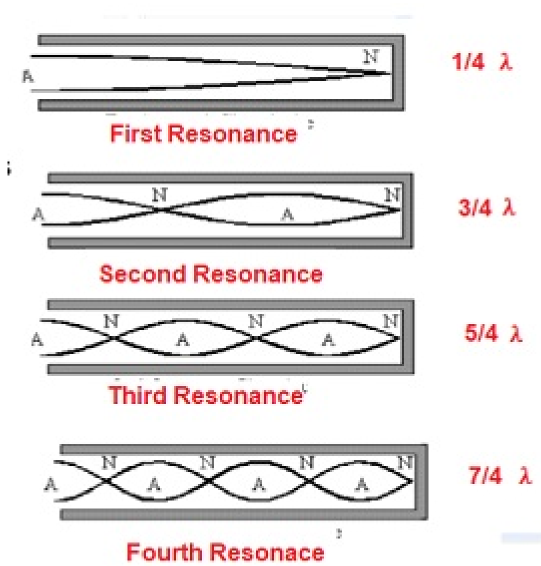
- Fitting in more of the wave produces different notes, different harmonics.

1) Closed At One End Column

A **closed ended** instrument has one end closed off, and the other end open. An example would be an instrument like some organ pipes (although in some designs they are open), or a flute

In the pipe there are TWO waves. One is leaving the fork and going down; the other is the reflected wave coming back from the bottom of the pipe. These two waves will interfere with each other to produce standing waves. Where the two waves interfere constructively, the air molecules will have a large displacement from their ordinary "rest" positions. Where air molecules are not so free to move they will interfere destructively.

Different antinodes are created at the mouth of the pipe, BUT ONLY AT THE PARTICULAR LENGTHS AS SHOWN. These resonant lengths are 1/4,3/4, 5/4,7/4 (and so on) of the wavelength of the sound.



We can use two formula's to determine the length and wavelength for each resonant frequency in a tube open at one end:

$$L_n = \frac{2n-1}{4}\lambda \qquad \lambda = \frac{4L_n}{2n-1}$$

Note that the expression (2n - 1) always has an "odd" value for tubes closed at one end.

Example 1:

On a nice summer day when the temperature is 23° C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?

Example 2:

You decide to impress Grandpa but showing him how fast sound travels. You have a piece of plastic pipe with an adjustable closed end, and a 312 Hz tuning fork. The piece of pipe resonates in the 2nd resonant length when it is adjusted to a length of 81.0 cm. What is the speed of sound on that day?

Example 3:

Tell Grandpa you are going to use the piece of plastic pipe in example 2 to measure the air temperature.

Example 4:

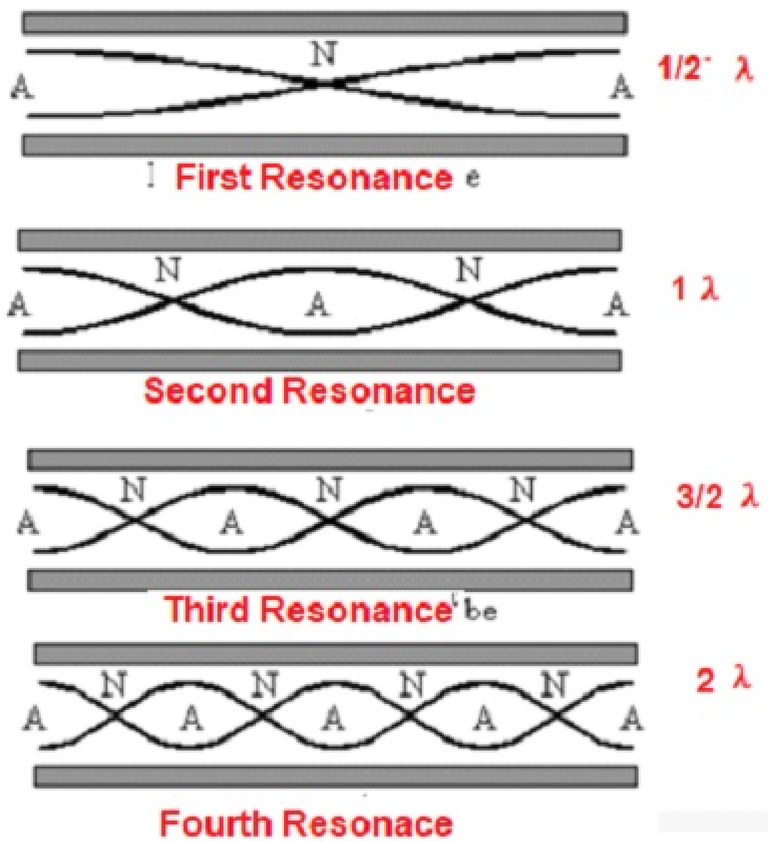
On a day when the speed of sound is 345 m/s, a 440 Hz tuning fork causes a tube closed at one end to vibrate in the second resonant length. How long is the tube?

Open At Both Ends Colum

An open ended instrument has both ends open to the air.

An example would be an instrument like a trumpet. You blow in through one end and the sound comes out the other end of the pipe

Since the pipe is opened at both ends, the air molecules at both ends can vibrate freely. (This could only happen at one end in the closed pipe). As the pipe is adjusted, the loops or antinodes must appear at the open ends as shown in the following diagrams



If you look closely, you will see another difference: for open air columns all the half wavelengths are resonant lengths; for the column closed at one end only the odd number of quarter wavelengths are resonant lengths.

We can use two formula’s to determine the length and wavelength for each resonant frequency in a tube open at both ends

$$L_n = \frac{n}{2}\lambda \quad \textbf{Or} \quad \lambda = \frac{2}{n}L_n$$

Note that can be ANY positive whole number for tubes OPENED at BOTH ends

The standing wave in an open column is similar to one in strings. The only difference is that standing waves in open columns have antinodes at the ends instead of node because particles are not fixed.

Example 5:

On a nice summer day when the temperature is 23° C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall and has NO BOTTOM. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?

Example 6:

When a 512 Hz tuning fork is sounded near one end of a tube opened at both ends, the difference between the 2nd and 5th resonant lengths is found to be 99 cm. What is the temperature of the air in the tube?

PART A: MULTIPLE CHOICE

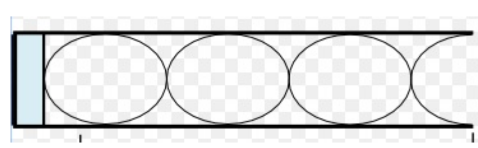
Instructions: *Instructions: Shade the letter of the correct answer on the computer scorable answer sheet provided.*

1. Sometimes a wind blows over the top of a pop bottle and a whistling sound is heard. What name best describes this phenomenon?

   (A) Beats
   (B) Interference
   (C) Resonance
   (D) Sonic boom

Use the diagram below to answer questions 2 and 6:

2. How many wavelengths are shown in the diagram?



   (A) 3/4
   (B) 5/4
   (C) 7/4
   (D) 9/4

3. How many nodes are shown?

   (A) 3
   (B) 4
   (C) 5
   (D) 6

4. How many antinodes are shown?

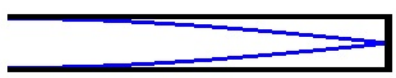
(A) 3
(B) 4
(C) 5
(D) 6

5. What is the resonant number?

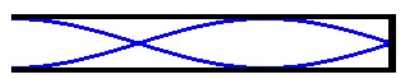
(A) n = 2
(B) n = 3
(C) n = 4
(D) n = 5

6. Which diagram represents one and three quarters os a wavelength in a column closed at one end?

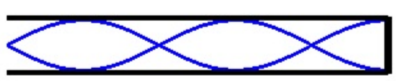
(A)



(B)



(C)



(D)

7. What distance does adjacent nodes formed in a resonating air column closed at one end ?

(A) One-quarter wavelength from one another
(B) One-quarter wavelength from each end
(C) One-half wavelength from one another
(D) One-half wavelength from each end

8. An air column closed at one end is vibrating in its third resonant length. If the wavelength of the sound is 80 cm, what is the length of the air column?

(A) 1 cm
(B) 1 m
(C) 120 cm
(D) 100 m

9. A standing wave with a fundamental mode wavelength of 60 cm forms in an air column closed at one end. How long is the column for the fundamental mode?

(A) 15 cm
(B) 30 cm
(C) 45 cm
(D) 60 cm

10. A tuning fork was held over a tube, open at one end only. The length of the tube was slowly increased until resonance was heard. If the first resonance was detected when the tube was 15 cm long, what length will give the next resonance?

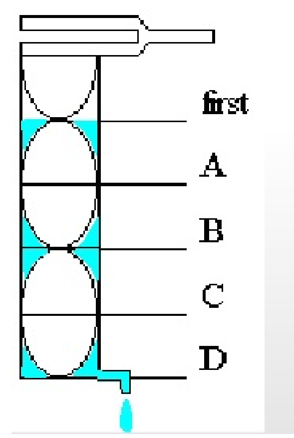
(A) 30 cm
(B) 45 cm
(C) 60 cm
(D 75 cm

11. In a lab experiment, using an adjustable tube closed at one end, two successive resonant lengths were found at 0.415 m and 0.580 m. Assuming the speed of sound is 340 m/s, what must be the frequency of the source?

(A) 515 Hz
(B) 687 Hz
(C) 1030 Hz
(D) 2060 Hz

12. The picture shows a tube, open at one end, and a tuning fork above the open end. The fork is sounded and water is slowly let out until the sound is noticeably louder. This position is noted as "first" in the picture. If the water continues to slowly drain out, at which level will the sound NEXT sound louder?

(A) A
(B) B
(C) C
(D) D



13. An empty pop bottle is to be used as a musical instrument in a band. In order to be tuned properly the fundamental frequency of the bottle must be 440.0Hz. If the bottle is 0.260 m tall, how high should it be filled with water to produce the desired frequency if the speed of sound in air is 343 m/s?

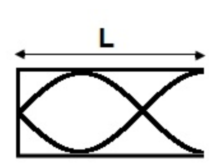
(A) 0.065 m
(B) 0.120 m
(C) 0.195 m
(D) 0.260 m

14. A sound wave resonates in a tube with one open end and a length L. What are the wavelengths of the first three resonant lengths generated in the tube?

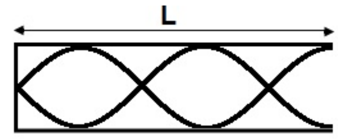
(A) L, 2L, 3L
(B) L, 2L, 2L/3
(C) L/2, L/3, L/5
(D) 4L, 4L/3, 4L/5

15. A sound wave resonates in a closed pipe at one end with a length of 3.0m as shown below. What is the wavelength of the wave?

(A) 2.0 m
(B) 3.0 m
(C) 4.0 m
(D) 6.0 m

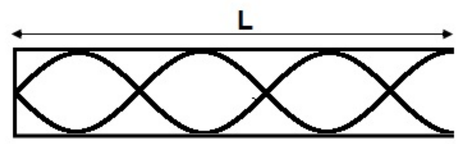


16. A sound wave resonates in a closed pipe at one end with a length of 3.5 m as shown below. What is the wavelength of the wave?



(A) 1.5 m
(B) 2.0 m
(C) 2.5 m
(D) 2.8 m

17. As shown below, a sound wave resonates in a closed pipe at one end with a length of 2.5 m. What is the resonating frequency? (Vsound = 340 m/s)

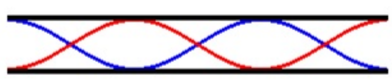
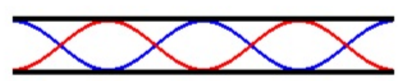
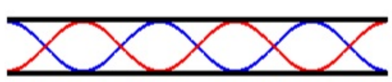
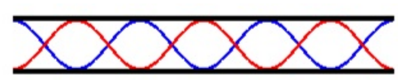


(A) 85 Hz
(B) 170 Hz
(C) 240 Hz
(D) 510 Hz

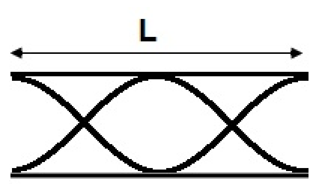
18. What instrument would involve an air column opened at both ends?

(A) Clarinet
(B) Flute
(C) Guitar
(D) Violin

19. Which diagram represents two and a half waves lengths in a column open at both ends?

(A) 	(B) 
(C) 	(D) 

Use the diagram below to answer questions 20 and 21:



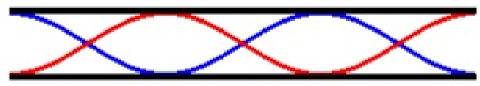
20. A sound wave resonates in an open pipe with a length of 1.0 m. What is the wavelength of the wave?

(A) 0.5 m
(B) 1.0 m
(C) 1.5 m
(D) 2.0 m

21. A sound wave resonates in an open pipe with a length of 2.0 m. What is the resonating frequency? (Vsound = 340 m/s)

(A) 85 Hz
(B) 170 Hz
(C) 340 Hz
(D) 510 Hz

Use the diagram below to answer questions 22 and 25:



22. How many wavelengths are shown in the diagram?

(A) 1/2
(B) 1
(C) 3/2
(D) 2

23. How many antinodes are shown?

(A) 3
(B) 4
(C) 5
(D) 6

24. How many nodes are shown?

(A) 3
(B) 4
(C) 5
(D) 6

25. What is the resonant number?

(A) n = 2
(B) n = 3
(C) n = 4
(D) n = 5

26. A sound wave resonates in a tube with two open ends and a length L. What are the wavelengths of the three lowest resonating lengths generated in the tube?

(A) L, 2L, 3L
(B) 2L, L, 2L/3
(C) L/2, L, 3L/2
(D) L/3, L/5, L/7

27. A tuning fork was held over a tube, open at both ends. The length of the tube was slowly increased until resonance was heard. If the first resonance was detected when the tube was 15 cm long, what length will give the next resonance?

(A) 30 cm
(B) 45 cm
(C) 60 cm
(D) 75 cm

PART B: WRITTEN RESPONSE

1. When a tuning fork is sounded above an adjustable column of air, the air inside the column can be made to resonate. Briefly compare and contrast resonance in open versus closed columns (use diagrams in your answer).

2. 310 Hz tuning fork is held over the mouth of an air column open at one end. If the speed of sound is 352 m/s, calculate the length of the air column which produces the second resonant sound

3. When a tuning fork is held over an adjustable tube open at both ends, the distance between the 1^{st} and 2^{nd} resonant lengths is measured to be 0.12 m.

   (i) Draw the standing wave pattern for the 1st and 2nd resonant length

   (ii) What is the wavelength of the sound causing the resonance?

4. A 440 Hz tuning fork is held over an air column that is open at one end. If the temperature is 19° C, calculate the length of the air column that produces the second resonant sound.

5. A 145 Hz tuning fork is held over the open end of an adjustable air column that is closed at the other end. The speed of sound in the air column is 345 m/s.

   (i) Sketch the first two resonant patterns produced inside the air column.

   (ii) Calculate the length of the air column which produces the second resonant sound.