#42 Sound Waves Pre-Class

Due: 11:00am on Monday, December 3, 2012

Note: You will receive no credit for late submissions. To learn more, read your instructor's Grading Policy

What Is a Sound Wave?

Learning Goal:

To understand the nature of a sound wave, including its properties: frequency, wavelength, loudness, pitch, and timbre.

Sound is a phenomenon that we experience constantly in our everyday life. Therefore, it is important to understand the physical nature of a sound wave and its properties to correct common misconceptions about sound propagation.

Most generally, a sound wave is a longitudinal wave that propagates in a medium (i.e., air). The particles in the medium oscillate back and forth along the direction of motion of the wave. This displacement of the particles generates a sequence of compressions and rarefactions of the medium. Thus, a sound wave can also be described in terms of pressure variations that travel through the medium. The pressure fluctuates at the same frequency with which the particles' positions oscillate.

When the human ear perceives sound, it recognizes a series of pressure fluctuations rather than displacements of individual air particles.

Part A

Based on the information presented in the introduction of this problem, what is a sound wave?

ANSWER:

- ○ Propagation of sound particles that are different from the particles that comprise the medium
- ○ Propagation of energy that does not require a medium
- ◉ Propagation of pressure fluctuations in a medium
- ○ Propagation of energy that passes through empty spaces between the particles that comprise the medium

Correct

Part B

Having established that a sound wave corresponds to pressure fluctuations in the medium, what can you conclude about the direction in which such pressure fluctuations travel?

ANSWER:

- The direction of motion of pressure fluctuations is independent of the direction of motion of the sound wave.
- Pressure fluctuations travel perpendicularly to the direction of propagation of the sound wave.
- Pressure fluctuations travel along the direction of propagation of the sound wave.

Correct

Part C

Does air play a role in the propagation of the human voice from one end of a lecture hall to the other?

Hint 1. Sound propagates in a medium

Sound is a mechanical wave. As such, it needs a medium to travel. Air is the medium through which the human voice usually propagates.

ANSWER:

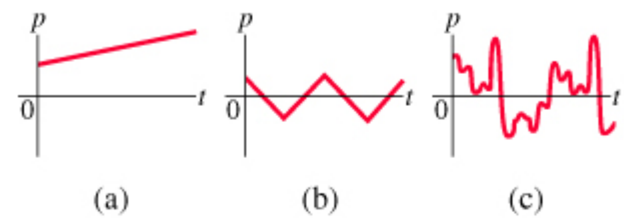
- yes
- no

Correct

Part D

The graphs shown here represent pressure variation versus time recorded by a microphone. Which could correspond to a sound wave?

Enter the letters of all the correct answers in alphabetical order. Do not use commas. For example, if you think all three graphs could represent sound waves, enter `ABC`.



Hint 1. Sound as propagation of pressure fluctuations

Sound propegation is the displacement of particles along the direction of motion of the sound wave which generates a sequence of compressions and rarefactions of a medium. Thus, a sound wave can be described in terms of pressure variations or fluctuations. It follows that a steady increase or decrease in pressure does not correspond to a sound wave.

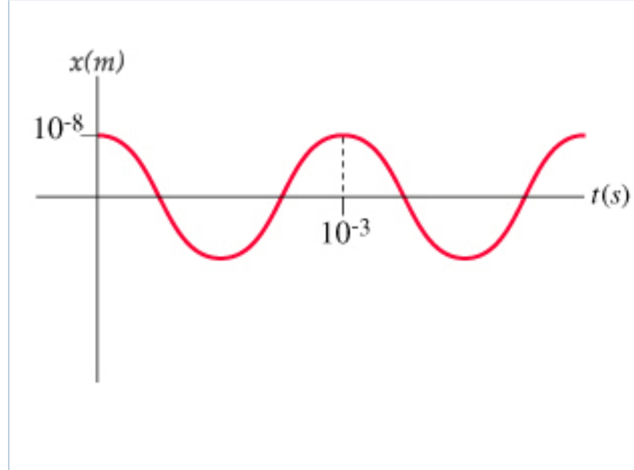
ANSWER:

BC

Correct

Part E

The next graph shows a sound wave consisting of a sinusoidal displacement of air particles versus time, as recorded at a fixed location. For sinusoidal waves, it is possible to identify a specific frequency (rate of oscillation) and wavelength (distance in space corresponding to one complete cycle).



Taking the speed of sound in air to be 344 $\mathrm{m/s}$, what are the frequency f and the wavelength λ of the sound wave shown in the graph?

Express your answers in, respectively, hertz and meters to three significant figures. Separate the two answers with a comma.

Hint 1. Definition of frequency

The frequency of a periodic wave is the number of complete oscillations per unit time.

Hint 2. Definition of wavelength

In a periodic wave pattern, the distance from one crest to the next (or alternatively from one trough to the next one or from any point to the corresponding point on the next oscillation cycle) is called wavelength and it is typically denoted by λ. In addition, the speed v at which the wave pattern propagates is given by

$$v = \lambda f,$$

where f is the frequency of the wave.

ANSWER:

f, λ = 1000,0.344 $\mathrm{Hz, m}$

Correct

Part F

A certain sound is recorded by a microphone. The same microphone then detects a second sound, which is identical to the first one except that the amplitude of the pressure fluctuations is larger. In addition to the larger amplitude, what distinguishes the second sound from the first one?

Hint 1. Amplitude of a sound wave

For a given frequency, the greater the amplitude of a sound wave, the louder it is perceived.

ANSWER:

- It is perceived as higher in pitch.
- It is perceived as louder.
- It has a higher frequency.
- It has a longer wavelength.

Correct

Part G

A certain sound is recorded by a microphone. The same microphone then detects a second sound, which is identical to the first one except that it has twice the frequency. In addition to the higher frequency, what distinguishes the second sound from the first one?

Hint 1. Frequency of a sound wave

The frequency of a sound wave is what mainly determines the pitch of that sound. The higher the frequency of a sound wave, the higher in pitch it is perceived.

ANSWER:

- (selected) It is perceived as higher in pitch.
- It is perceived as louder.
- It has a higher amplitude.
- It has a longer wavelength.

Correct

When we double the frequency of a sound wave, we produce a sound that is said to be an *octave* above the first.

Part H

What varies between two tones that are different in timbre, that is, two tones that have the same fundamental frequency but are produced, say, by different musical instruments?

Note that Figures (b) and (c) from Part D could represent tones with different timbre.

Hint 1. Timbre

The quality of a sound is related to the harmonic content of that sound. Harmonics are higher frequency components of a sound that are integer multiples of a sound's fundamental frequency. A tone that is rich in harmonics has a different quality from one that contains mainly the fundamental frequency, even if the fundamental frequencies of the two sounds are the same. This difference is also called tone color.

ANSWER:

- the pitch
- the harmonic content
- nothing

Correct

± The Decibel Scale

Learning Goal:

To understand the decibel scale.

The decibel scale is a logarithmic scale for measuring the sound intensity level. Because the decibel scale is logarithmic, it changes by an additive constant when the intensity as measured in $\mathrm{W/m^2}$ changes by a multiplicative factor. The number of decibels increases by 10 for a factor of 10 increase in intensity.

The general formula for the sound intensity level, in decibels, corresponding to intensity I is

$$\beta = 10\,\log\left(\frac{I}{I_0}\right)\,\mathrm{dB},$$

where I_0 is a reference intensity. For sound waves, I_0 is taken to be $10^{-12}\,\mathrm{W/m^2}$. Note that $\log$ refers to the logarithm to the base 10.

Part A

What is the sound intensity level β, in decibels, of a sound wave whose intensity is 10 times the reference intensity (i.e., $I = 10I_0$)?

Express the sound intensity numerically to the nearest integer.

Hint 1. Evaluate the logarithm

If $I = 10I_0$, the argument of the log function in the definition of the dB scale is simply 10. What is the value of $\log(10)$?

Express your answer numerically.

ANSWER:

$\log(10)$ =

- 0
- (selected) 1
- 2.30
- 10

ANSWER:

β = 10 dB

Correct

Part B

What is the sound intensity level β, in decibels, of a sound wave whose intensity is 100 times the reference intensity (i.e. $I = 100I_0$)?

Express the sound intensity numerically to the nearest integer.

Hint 1. Evaluate the logarithm

If $I = 100 I_0$, the argument of the log function in the definition of the dB scale is 100. What is the value of $\log(100)$?

Express your answer numerically.

ANSWER:

$\log(100)$ =

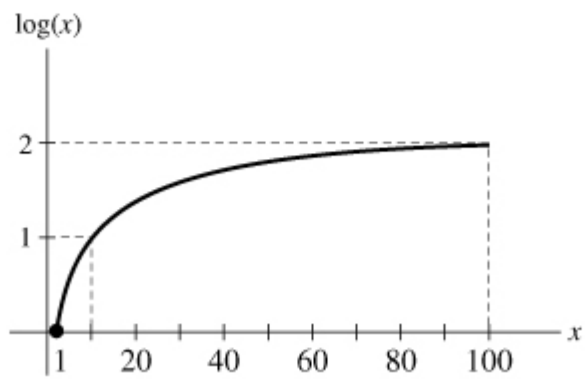
- 2
- 4.60
- 10
- 20

ANSWER:

β = 20 dB

Correct

The answers to Parts A and B demonstrate the essence of the dB scale--every 10 dB indicates a factor of 10 increase in the sound intensity level, so an increase in 20 dB indicates a factor of $10^2 = 100$ increase in intensity. A graph of $\log(x)$ vs. x is shown below to support this idea.



The ability of the ears of animals (including humans) to be sensitive to 1 dB (or even less for some animals) and yet not be permanently damaged by 120 dB (a million million times the intensity) is remarkable.

One often needs to compute the change in decibels corresponding to a change in the physical intensity measured in units of power per unit area. Take m to be the factor of increase of the physical intensity (i.e., $I = mI_0$).

Part C

Calculate the change in decibels ($\Delta\beta_2$, $\Delta\beta_4$, and $\Delta\beta_8$) corresponding to $m = 2$, $m = 4$, and $m = 8$.

Give your answers, separated by commas, to the nearest integer--this will give an accuracy of 20%, which is good enough for sound.

Hint 1. How to approach the problem

To find the increase take I_0 in the general formula to be the *initial* intensity and then take I to be the factor of increase: $I = mI_0$. Then, $\log(I/I_0) = \log(m)$ and the change in intensity measured in decibels is $10\log(m)$.

ANSWER:

$\Delta\beta_2$, $\Delta\beta_4$, $\Delta\beta_8$ = 3,6,9 dB

Correct

± The Hearing of a Bat

Bats are mainly active at night. They have several senses that they use to find their way about, locate prey, avoid obstacles, and "see" in the dark. Besides the usual sense of vision, bats are able to emit high-frequency sound waves and hear the echo that bounces back when these sound waves hit an object. This sonar-like system is called echolocation. Typical frequencies emitted by bats are between 20 and 200 kHz. Note that the human ear is sensitive only to frequencies as high as 20 kHz.

A moth of length 1.0 cm is flying about 1.0 m from a bat when the bat emits a sound wave at 80.0 kHz. The temperature of air is about 10.0$^\circ\mathrm{C}$. To sense the presence of the moth using echolocation, the bat must emit a sound with a wavelength equal to or less than the length of the insect.

The speed of sound that propagates in an ideal gas is given by

$$v = \sqrt{\frac{\gamma RT}{M}},$$

where γ is the ratio of heat capacities ($\gamma = 1.4$ for air), T is the absolute temperature in kelvins (which is equal to the Celsius temperature plus 273.15$^\circ\mathrm{C}$), M is the molar mass of the gas (for air, the average molar mass is $M = 28.8 \times 10^{-3}\ \mathrm{kg/mol}$), and R is the universal gas constant ($R = 8.314\ \mathrm{J \cdot mol^{-1} \cdot K^{-1}}$).

Part A

Find the wavelength λ of the 80.0-kHz wave emitted by the bat.

Express your answer in millimeters.

Hint 1. Relating wavelength, frequency, and speed of a wave

In periodic waves, the speed at which the wave pattern travels is given by

$$v = \lambda f,$$

where λ is the wavelength and f is the frequency of the wave.

Hint 2. Find the speed of sound in air

Find the speed of sound v in air at 10.0$^\circ\mathrm{C}$.

Express your answer in meters per second.

ANSWER:

v = 338 $\mathrm{m/s}$

ANSWER:

λ = 4.23 mm

Correct

Part B

Will the bat be able to locate the moth despite the darkness of the night?

ANSWER:

- (selected) yes
- no

Correct

Part C

How long after the bat emits the wave will it hear the echo from the moth?

Express your answer in milliseconds to two significant figures.

Hint 1. How to approach the problem

After emitting the high-frequency sound, the bat waits for any echoes coming back from possible obstacles. Therefore the time needed to locate an obstacle depends on the speed of sound and the distance of the obstacle from the bat.

Hint 2. Find the time needed for the sound wave to reach the moth

How long does it take the sound wave to reach the moth?

Express your answer in milliseconds to three significant figures.

ANSWER:

2.96 ms

ANSWER:

5.9 ms

Correct

Open Organ Pipe Conceptual Question

An open organ pipe (i.e., a pipe open at both ends) of length L_0 has a fundamental frequency f_0.

Part A

If the organ pipe is cut in half, what is the new fundamental frequency?

Hint 1. Fundamental wavelength in an open pipe

For a wave in an open pipe, the fundamental wavelength is the longest wave that "fits" in the pipe, with an antinode (point of maximum wave amplitude) at both open ends.

Hint 2. Fundamental frequency

For speed of sound v_s, wavelength λ, and frequency f,

$$v_s = \lambda f,$$

so the frequency of a wave is given by

$$f = \frac{v_s}{\lambda}.$$

Thus, the fundamental frequency and the fundamental wavelength are inversely proportional.

ANSWER:

- $4f_0$
- $2f_0$
- f_0
- $f_0/2$
- $f_0/4$

Correct

Part B

After being cut in half in Part A, the organ pipe is closed off at one end. What is the new fundamental frequency?

Hint 1. Fundamental wavelength in a closed pipe

For a wave in a closed pipe, the fundamental wavelength is the longest wave that "fits" in the pipe, with an antinode (point of maximum wave amplitude) at the open end and a node (point of zero wave amplitude) at the closed end.

ANSWER:

- $4f_0$
- $2f_0$
- f_0
- $f_0/2$
- $f_0/4$

Correct

The fundamental frequency of a half-length closed pipe is equal to that of a full-length open pipe.

Part C

The air from the pipe in Part B (i.e., the original pipe after being cut in half and closed off at one end) is replaced with helium. (The speed of sound in helium is about three times faster than in air.). What is the approximate new fundamental frequency?

Hint 1. The role of the speed of sound

In an organ pipe, the wave speed is the speed of sound. For speed of sound v_s, frequency f, and wavelength λ,

$$v_s = \lambda f.$$

Thus, the frequency of a wave is directly proportional to the wave speed.

ANSWER:

- ◉ $3f_0$
- ○ $2f_0$
- ○ f_0
- ○ $f_0/2$
- ○ $f_0/3$

Correct

Based on your answer to this part, can you explain why you have a high pitched voice after inhaling the helium from a helium balloon?

Introduction to Wind Instruments

The physics of wind instruments is based on the concept of standing waves. When the player blows into the mouthpiece, the column of air inside the instrument vibrates, and standing waves are produced. Although the acoustics of wind instruments is complicated, a simple description in terms of open and closed tubes can help in understanding the physical phenomena related to these instruments. For example, a flute can be described as an open-open pipe because a flutist covers the mouthpiece of the flute only partially. Meanwhile, a clarinet can be described as an open-closed pipe because the mouthpiece of the clarinet is almost completely closed by the reed.

Throughout the problem, take the speed of sound in air to be 343$\mathrm{m/s}$.

Part A

Consider a pipe of length 80.0cm open at both ends. What is the lowest frequency f of the sound wave produced when you blow into the pipe?

Express your answer in hertz.

Hint 1. How to approach the problem

The lowest frequency that can be produced is the fundamental frequency of the standing wave in the pipe.

Hint 2. Frequencies of standing waves in an open-open pipe

The frequencies possible in an open-open pipe of length L are given by the formula

$$f_m = m\frac{v}{2L}, \quad m = 1, 2, 3, 4, \ldots,$$

where v is the speed of sound in the air.

ANSWER:

f = 214 Hz

Correct

If your pipe were a flute, this frequency would be the lowest note that can be produced on that flute. This frequency is also known as the fundamental frequency or first harmonic.

Part B

A hole is now drilled through the side of the pipe and air is blown again into the pipe through the same opening. The fundamental frequency of the sound wave generated in the pipe is now

Hint 1. How to approach the problem

Since the hole opens the pipe to the pressure of the surrounding air, the standing wave created in the pipe has an antinode near the hole. In other words, the presence of a hole in the pipe reduces the length of the column of air that can oscillate in the pipe.

Consider the formula used in Part A and use the fact that the length of the vibrating column of air is now *shorter*.

ANSWER:

- the same as before.
- lower than before.
- higher than before.

Correct

By opening successive holes closer and closer to the opening used to blow air into the pipe, the pipe can be made to produce sound at higher and higher frequencies. This is what flutists do when they open the tone holes on the flute.

Part C

If you take the original pipe in Part A and drill a hole at a position half the length of the pipe, what is the fundamental frequency f' of the sound that can be produced in the pipe?

Express your answer in hertz.

Hint 1. How to approach the problem

Repeat the same calculation you did in Part A, this time using half the length of the pipe.

ANSWER:

f' = 429 Hz

Correct

Part D

What frequencies, in terms of the fundamental frequency of the original pipe in Part A, can you create when blowing air into the pipe that has a hole halfway down its length?

Hint 1. How to approach the problem

Recall from the discussion in Part B that the standing wave produced in the pipe must have an antinode near the hole. Thus only the harmonics that have an antinode halfway down the pipe will still be present.

ANSWER:

- ○ Only the odd multiples of the fundamental frequency
- ◉ Only the even multiples of the fundamental frequency
- ○ All integer multiples of the fundamental frequency

Correct

Part E

What length of open-closed pipe would you need to achieve the same fundamental frequency f as the open-open pipe discussed in Part A?

Hint 1. Frequencies on an open-closed pipe

The frequencies possible in an open-closed pipe of length L are given by

$$f_m = m\frac{v}{4L}, \quad m = 1, 3, 5, \ldots,$$

where v is the speed of sound in the air.

ANSWER:

- Half the length of the open-open pipe
- Twice the length of the open-open pipe
- One-fourth the length of the open-open pipe
- Four times the length of the open-open pipe
- The same as the length of the open-open pipe

Correct

Part F

What is the frequency f'' of the first possible harmonic after the fundamental frequency in the open-closed pipe described in Part E?

Express your answer in hertz.

Hint 1. How to approach the problem

Recall that possible frequencies of standing waves that can be generated in an open-closed pipe include only *odd* harmonics. Then the first possible harmonic after the fundamental frequency is the third harmonic.

ANSWER:

f'' = 643 Hz

Correct

Score Summary:

Your score on this assignment is 100.1%.
You received 25.03 out of a possible total of 25 points.