Name ___________________________

Sound Group Problem Set. Show all work and calculations

Doppler Effect

Vocabulary **Doppler Effect:** A change in the apparent frequency of sound due to the motion of the source of the receiver.

You probably associate the Doppler effect with the change in pitch (frequency) of a loud car or siren just as it passes you. The pitch suddenly drops just as the object moves by. Light can also be Doppler shifted but the Doppler shift of light will not be discussed in this chapter.

The equation that describes this effect can be used whether the source is approaching or receding from the observer. It also works if either the source or observer is at rest, or if there is a chase situation in which both are moving in the same direction.

$$\textbf{perceived frequency} = \textbf{actual frequency}\,\frac{(\textbf{speed of sound} + \textbf{speed of observer})}{(\textbf{speed of sound} - \textbf{speed of source})}$$

or $$f = f_o \frac{(v + v_o)}{(v - v_s)}$$

Here, f_o refers to the actual frequency being emitted by an object, while f is the frequency heard by the observer as the source approaches or recedes. If a source approaches, the perceived frequency will be higher than the actual frequency. If a source recedes, the perceived frequency is lower than the actual frequency.

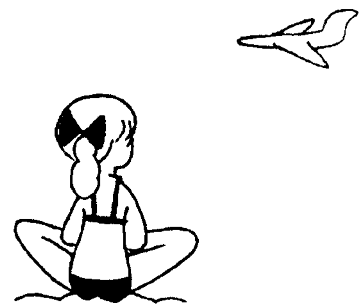
In order for this equation to work properly, there is a standard convention to which you must adhere whenever solving Doppler exercises.

v_o is (+) if the observer moves toward the source.
v_o is (−) if the observer moves away from the source.
v_s is (+) if the source moves toward the observer.
v_s is (−) if the source moves away from the observer.

Remember, it is not necessary to always have both the observer and the source in motion. Often one will be moving and the other will be at rest.

Solved Examples

Example 3: Sitting on the beach at Coney Island one afternoon, Sunny finds herself beneath the flight path of the airplanes leaving Kennedy Airport. What frequency will Sunny hear as a jet, whose engines emit sound at a frequency of 1000. Hz, flies toward her at a speed of 100.0 m/s?



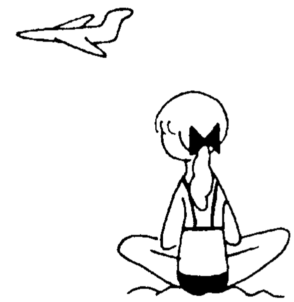
Solution: First draw a diagram of the situation. Notice in the calculation below that Sunny is sitting at rest and the plane is approaching. Therefore, the source is moving toward the observer. The observer remains stationary.

Given: $f_o = 1000.\ \text{Hz}$
$v_o = 0\ \text{m/s}$
$v = 340.\ 0\ \text{m/s}$
$v_s = 100.0\ \text{m/s}$

Unknown: $f = ?$
Original equation: $f = f_o \dfrac{(v + v_o)}{(v - v_s)}$

Solve: $f = f_o \dfrac{(v + v_o)}{(v - v_s)} = 1000.\ \text{Hz} \dfrac{(340.0\ \text{m/s} + 0\ \text{m/s})}{(340.0\ \text{m/s} - 100.0\ \text{m/s})} = \mathbf{1417\ Hz}$

Example 4: In the previous example, what frequency will Sunny observe as the jet travels away from her at the same speed?



Solution: Again, draw a diagram of the situation. This time, the source is moving away from the observer, so the value for v_s must be negative.

Given: $f_o = 1000.\text{ Hz}$
$v_o = 0\text{ m/s}$
$v = 340.0\text{ m/s}$
$v_s = -100.0\text{ m/s}$

Unknown: $f = ?$
Original equation: $f = f_o \dfrac{v + v_o}{v - v_s}$

Solve: $f = f_o \dfrac{(v + v_o)}{(v - v_s)} = 1000.\text{ Hz} \dfrac{(340.0\text{ m/s} + 0\text{ m/s})}{(340.0\text{ m/s} - [-100.0\text{ m/s}])} = \mathbf{772.7\ Hz}$

Example 5: A sparrow chases a crow with a speed of 4.0 m/s, while chirping at a frequency of 850.0 Hz. What frequency of sound does the crow hear as he flies away from the sparrow with a speed of 3.0 m/s?

Given: $f_o = 850.0\text{ Hz}$
$v_o = -3.0\text{ m/s}$
$v = 340.0\text{ m/s}$
$v_s = 4.0\text{ m/s}$

Unknown: $f = ?$
Original equation: $f = f_o \dfrac{(v + v_o)}{(v - v_s)}$

Solve: $f = f_o \dfrac{(v + v_o)}{(v - v_s)} = 850.0\text{ Hz} \dfrac{(340.0\text{ m/s} + [-3.0\text{ m/s}])}{(340.0\text{ m/s} - 4.0\text{ m/s})} = \mathbf{852.5\ Hz}$

Therefore, since the sparrow is approaching the crow, the crow hears a frequency that is higher than the original.

Standing Waves

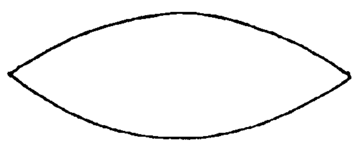
Waves in Strings

When a string is plucked, a wave will reflect back and forth from one end of the string to the other, creating **nodes** (points of minimum movement) and **antinodes** (points of maximum movement). This is called a **standing wave** because it appears to stand still.

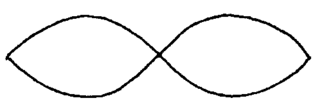
The frequency with which a string vibrates depends upon the number of antinodes, the wave speed, and the length of the string, as shown in the following relationship.

$$\textbf{frequency} = \frac{(\textbf{number of antinodes})(\textbf{wave speed})}{\textbf{2}(\textbf{length})} \quad \text{or} \quad f = \frac{nv}{2L}$$

If $n = 1$, as shown in the diagram, the frequency is called the **fundamental frequency.** It is the lowest frequency of a vibrating string that is fixed at both ends. Multiples of the fundamental frequency are called **overtones.**



First overtone



$$f = \frac{2v}{} = \frac{v}{L}$$

Second overtone

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

Third overtone

$$f = \frac{4v}{} = \frac{2v}{L}$$

and so on.

Waves in Pipes

Waves in pipes that are open at both ends behave much like waves in strings. It is important to remember that antinodes always form at open ends of a pipe while nodes form at closed ends. If a pipe is open at both ends, the possible frequencies are

$$f = \frac{nv}{2L} \qquad \text{(where } n = 1, 2, 3 \ldots \text{ for other overtones)}$$

In a pipe that is closed at one end, the possible frequencies are

$$f = \frac{nv}{4L} \quad \text{(where } n = 1, 3, 5, 7 \ldots \text{ for other overtones)}$$

Beats

If two different frequencies sound simultaneously, the wavelengths will differ, and the crests and troughs of each wave will overlap in a way that causes variations in loudness. There will be moments of reinforcement and moments of cancellation as the wave patterns interact. The resulting sound is a series of **beats,** which occur when the wave sum reaches its greatest amplitude.

The beat frequency can be found by taking the absolute value of the difference between the two frequencies of the interacting waves.

$$f_{\text{beat}} = |f_1 - f_2|$$

Solved Examples

Example 6: An orchestra tunes up for the big concert by playing an A, which resounds with a fundamental frequency of 440. Hz. Find the first and second overtones of this note.

The first overtone is 2 times the fundamental frequency:

$$f_2 = 2f_0 \quad \text{so} \quad f_2 = 2(440.\ \text{Hz}) = \mathbf{880.\ Hz}$$

The second overtone is 3 times the fundamental frequency:

$$f_3 = 3f_0 \quad \text{so} \quad f_3 = 3(440.\ \text{Hz}) = \mathbf{1320\ Hz}$$

Example 7: Zeke plucks a C on his guitar string, which vibrates with a fundamental frequency of 261 Hz. The wave travels down the string with a speed of 400. m/s. a) What is the length of the guitar string? b) Would Zeke need longer or shorter strings to play the fundamental frequency for higher notes?

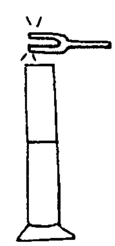
a. *Given:* $n = 1$
$v = 400.\ \text{m/s}$
$f = 261\ \text{Hz}$

Unknown: $L = ?$
Original equation: $f = \dfrac{nv}{2L}$

Solve: $L = \dfrac{nv}{2f} = \dfrac{(1)(400.\ \text{m/s})}{2(261\ \text{Hz})} = \mathbf{0.766\ m}$

b. If the wave speed remains the same for each string, as f gets larger, L gets smaller. Therefore, the higher the note, the shorter the string required to hear the fundamental frequency.

Example 8: In his physics lab, Sanjiv finds that he can take a long glass tube and fill it with water, using the air space at the top to simulate a pipe closed at one end. If Sanjiv holds a tuning fork, which vibrates with a fundamental frequency of 440 Hz, over the mouth of the pipe, how long is the air column if it vibrates at the same frequency?



Given: $f = 440\ \text{Hz}$
$v = 340.0\ \text{m/s}$
$n = 1$

Unknown: $L = ?$
Original equation: $f = \dfrac{nv}{4L}$

Solve: $L = \dfrac{nv}{4f} = \dfrac{(1)(340.0\ \text{m/s})}{4(440\ \text{Hz})} = \mathbf{0.19\ m}$

Solve Problems on a separate sheet of paper and attach.

A-1: Find the wavelength of the ultrasonic wave emitted by a bat if it has a frequency of 4.0 10^4 Hz.

A-2: Radio station KSON in San Diego broadcasts at both 1240 kHz (AM) and 97.3 MHz (FM). a) Which of these signals, AM or FM, has the longer wavelength? b) How long is each?

A-3: What is the wavelength of a B note (frequency 494 Hz) played a) by a flute? b) If the flute and a sax play the same note, which of the following will be different: quality, pitch, or loudness?

A-4: As an anchor is being hoisted out of the water, it hits the hull of the ship, causing the anchor to vibrate with a frequency of 150. Hz. If the speed of sound in sea water is 1520 m/s, how many wavelengths of sound will fit between the boat and the ocean bottom 395 m below?

A-5: A popular pastime at sporting events is “the wave,” a phenomenon where individuals in the crowd stand up and sit down in sequence, causing a giant ripple of people. If a continuous “wave” passes through a stadium of people with a speed of 20 m/s and a frequency of 0.5 Hz, what is the distance from “crest” to “crest” (in other words, the wavelength of the wave)?

A-6: From his bedroom, Garth can hear the distant sound of a train horn as the train travels through the mountains on its way from Chattanooga to Nashville. The horn has a frequency of 800.0 Hz as the train rolls along at 20.00 m/s. What frequency does Garth hear as the train travels away?

A-7: Erin is late to physics class and is coming down the hall as the bells are ringing. There are two bells in the hall, one at the far end, and one in front of the classroom she is approaching. Each rings with a frequency of 500.0 Hz. As Erin comes down the hallway with a speed of 1.000 m/s toward the classroom a) what frequency does she hear for each bell? b) What beat frequency does she hear?

A-8: Karen flies a motorized toy airplane with a frequency of 200. Hz in a circle at a speed of 18.0 m/s. Caroline stands nearby and hears a Doppler shift as the plane approaches and recedes from her. What are the a) highest and b) lowest frequencies Caroline hears?

A-9: Sonar detectors work by bouncing high-frequency sound waves of about 0.100 MHz off oncoming ships and detecting the frequency of the return signal. If a sonar detector receives a return signal of 0.101 MHz from a sub, how fast is the sub going? (*Hint:* Sonar travels in sea water at 1520 m/s.)

A-10: A fly traveling at 3.000 m/s is pursued by a bat traveling at 6.000 m/s who emits sound at an ultrasonic frequency of 50,000. Hz. If the fly could detect such a high frequency emission, what frequency would the fly hear as it is being pursued?

A-11: Lars is jogging beside the railroad tracks at a speed of 2.00 m/s when he hears a train whistle behind him at a frequency of 2115 Hz. If the actual frequency of the train whistle is 2000. Hz, how fast is the train moving?

A-12: Walter is a bass and can hit a low E that has a frequency of 82.4 Hz. Millie is a soprano and can sing as high as the third overtone of this note. What is the highest frequency that Millie can sing?

A-13: Joyce, the church organist, is practicing on the organ and she finds that the first two overtones for the 370-Hz pipe are 1110 Hz and 1850 Hz. Is the organ pipe closed at one end or open at both ends?

A-14: A train passes through a tunnel that is 550 m long. What is the fundamental frequency of vibrating air in the tunnel?

A-15: Harvey, a harpist, plucks a 0.600-m-long string on his harp. The string has a first overtone of 1046.6 Hz. How fast does the vibration travel through the string?

A-16: Reed arrives late to practice and finds that the orchestra has already tuned up and begun to play. As one oboist hits a D with a frequency of 293.7 Hz, Reed plays a note with a frequency of 291.2 Hz. What beat frequency is heard as the two instruments are playing side by side?

Challenge Exercises for Further Study

B-1: As a train approaches a ringing crossing gate, Stacey, a passenger on the train, hears a frequency of 440 Hz from the bell. As the train recedes, she hears a frequency of 410 Hz. How fast is the train traveling?

B-2: Richard stands on the flatbed car of a moving train playing an A on his horn. The note has a fundamental frequency of 220 Hz. Calculate whether or not the train could move fast enough for a stationary observer on the ground to hear the first overtone of the horn as the train passes.