Exercise 3: While flying to Tucson, Connie's plane experiences turbulence that causes the coffee in her cup to oscillate back and forth 4 times each second. If the waves of coffee have a wavelength of 0.1 m, what is the speed of a wave moving through the coffee?

Answer: ____________

Exercise 4: At a country music festival in New Hampshire, the Oak Ridge Boys are playing at the end of a crowded 184-m field when Ronny Fairchild hits a note on the keyboard that has a frequency of 400. Hz. a) How many full wavelengths are there between the stage and the last row of the crowd? b) How much delay is there between the time a note is played and the time it is heard in the last row?

Answer: **a.** ____________

Answer: **b.** ____________

12-2 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: $f_o = 1000.$ Hz
$v_o = 0$ m/s
$v = 340.0$ m/s
$v_s = 100.0$ m/s

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

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

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

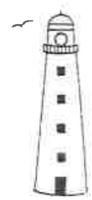
Unknown: $f = ?$
Original equation: $f = f_o \dfrac{(v + v_o)}{(v - v_s)}$

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.

Practice Exercises

Example 5: One foggy morning, Kenny is driving his speed boat toward the Brant Point lighthouse at a speed of 15.0 m/s as the fog horn blows with a frequency of 180.0 Hz. What frequency does Kenny hear as he moves?



Answer: ________________

Example 6: Dad is driving the family station wagon to Grandma's house when he gets tired and pulls over in a roadside rest stop to take a nap. Junior, who is sitting in the back seat, watches the trucks go by on the highway and notices that they make a different sound when they are coming toward him than they do when they are moving away. a) If a truck with a frequency of 85.0 Hz is traveling toward Junior with a speed of 27.0 m/s, what frequency does Junior hear as the truck approaches? b) After the truck passes, what frequency does Junior hear as the truck moves away?

Answer: **a.** ________________

Answer: **b.** ________________

Exercise 7: One way to tell if a mosquito is about to sting is to listen for the Doppler shift as the mosquito is flying. The buzzing sound of a mosquito's wings is emitted at a frequency of 1050 Hz. a) If you hear a frequency of 1034 Hz, does this mean that the mosquito is coming in for a landing or that it has just bitten you and is flying away? b) At what velocity is the mosquito flying?

Answer: **a.** ________________

Answer: **b.** ________________

Exercise 8: Barney, a bumblebee flying at 6.00 m/s, is being chased by Betsy, a bumblebee who is flying at 4.00 m/s. Barney's wings beat with a frequency of 90.0 Hz. What frequency does Betsy hear as she flies after Barney?

Answer: ____________

Exercise 9: Mrs. Gonzalez is about to give birth and Mr. Gonzalez is rushing her to the hospital at a speed of 30.0 m/s. Witnessing the speeding car, Officer O'Malley jumps in his police car and turns on the siren, whose frequency is 800. Hz. If the officer chases after the Gonzalez' car with a speed of 35.0 m/s, what frequency do the Gonzalezes hear as the officer approaches?

Answer: ____________

12-3 Standing Waves

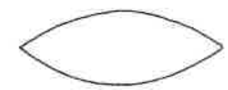
Waves in Strings

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.

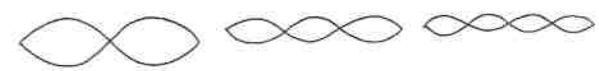
The frequency with which a string vibrates depends upon the number of antinodes, the wave speed, and the length of the string, as shown in the following relationship.

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

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 | **Second overtone** | **Third overtone**



$f = \frac{2v}{2L} = \frac{v}{L}$ | $f = \frac{3v}{2L}$ | $f = \frac{4v}{2L} = \frac{2v}{L}$

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

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

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.

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

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. 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: $f = \frac{nv}{2L}$

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

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: $f = \frac{nv}{4L}$

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

Practice Exercises

Exercise 10: Melody puts a fret on her guitar string, causing it to vibrate with a fundamental frequency of 250 Hz as a wave travels through at 350 m/s. a) How long is the guitar string from the lower fixed end to the fret? b) How far and in which direction must the fret be moved in order to produce a fundamental frequency that is twice as high (i.e., one octave higher)?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 11: The fundamental frequency of a bass violin string is 1045 Hz and occurs when the string is 0.900 m long. How far from the lower fixed end of the bass violin should you place your fingers to allow the string to vibrate at a fundamental frequency 3 times as great?

Answer: ____________________

Exercise 12: Aaron blows across the opening of a partially filled 20.0-cm-high soft drink bottle and finds that the air vibrates with a fundamental frequency of 472 Hz. How high is the liquid in the bottle?

Answer: ____________________