# #43 Doppler Effect and Shock Waves Pre-class

Due: 11:00am on Wednesday, December 5, 2012

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

## Doppler Shift

**Learning Goal:**

To understand the terms in the Doppler shift formula.

The Doppler shift formula gives the frequency $f_{\rm L}$ at which a listener L hears the sound emitted by a source S at frequency $f_{\rm S}$:

$$f_{\rm L} = f_{\rm S}\frac{v + v_{\rm L}}{v + v_{\rm S}},$$

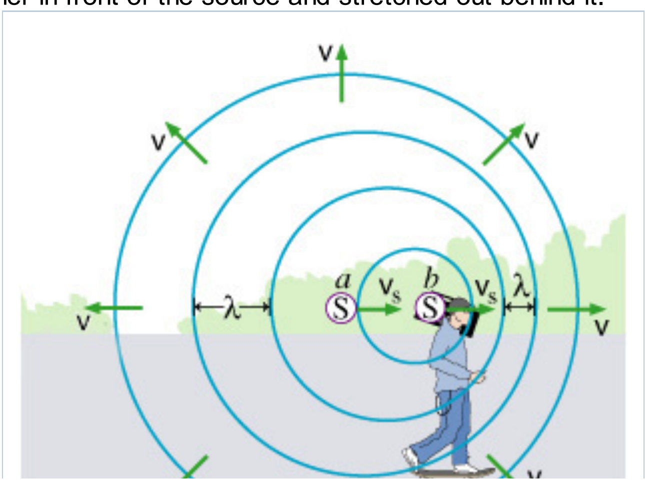
where $v$ is the speed of sound in the medium, $v_{\rm L}$ is the velocity of the listener, and $v_{\rm S}$ is the velocity of source.

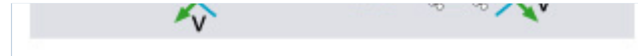
### Part A

The velocity of the source is positive if the source is ______________. Note that this equation may not use the sign convention you are accustomed to. Think about the physical situation before answering.

**Hint 1.** Relating the frequency and the source velocity

The figure below shows that wave crests emitted by a moving source are crowded together in front of the source and stretched out behind it. This means that the frequency heard by a listener in front of the source will be greater than the frequency of the source, and similarly, the frequency heard by a listener behind the source will be less than the frequency of the source. Use this information to determine the sign convention for the source velocity that, along with the formula given in the introduction, produces the correct frequency behavior.





ANSWER:

- traveling in the +*x* direction
- traveling toward the listener
- traveling away from the listener

**Correct**

## Part B

The velocity of the source is measured with respect to the ________.

ANSWER:

- medium (such as air or water)
- listener

**Correct**

## Part C

The velocity of the listener is positive if the listener is _____________.

**Hint 1.** Relating the frequency and the listener's velocity

A listener moving toward the source will run into more wave crests in a given time period than were emitted by the source (in the same period). So a listener moving toward the source will hear a higher frequency than the emitted frequency.
Similarly, a listener moving away from the source will hear a lower frequency than the emitted frequency.

Use this information to find the correct sign convention for the listener's velocity that goes with the supplied formula.

ANSWER:

- traveling in the +$x$ direction
- traveling toward the source
- traveling away from the source

**Correct**

---

### Part D

The velocity of the listener is measured with respect to the ________.

ANSWER:

- source
- medium

**Correct**

Here are two rules to remember when using the Doppler shift formula:

1. Velocity is measured *with respect to the medium.*
2. The velocities are *positive* if they are in the direction from the *listener to the source.*

## Part E

Imagine that the source is to the right of the listener, so that the positive reference direction (from the listener to the source) is in the $+x$ direction. If the listener is stationary, what value does $f_{\rm L}$ approach as the source's speed approaches the speed of sound moving to the right?

ANSWER:

- 0
- $\frac{1}{2}f_{\rm S}$
- $2f_{\rm S}$
- It approaches infinity.

**Correct**

## Part F

Now, imagine that the source is to the left of the listener, so that the positive reference direction is in the $-x$ direction. If the source is stationary, what value does $f_{\rm L}$ approach as the listener's speed (moving in the $+x$ direction) approaches the speed of sound?

ANSWER:

- 0
- $\frac{1}{2}f_{\rm S}$
- $2f_{\rm S}$
- It approaches infinity.

**Correct**

Basically in this case the listener doesn't hear anything since the sound waves cannot catch up with him or her.

### Part G

In this last case, imagine that the listener is stationary and the source is moving toward the listener at the speed of sound. (Note that it is irrelevant whether the source is moving to the right or to the left.) What is $f_L$ when the sound waves reach the listener?

ANSWER:

- 0
- $\frac{1}{2}f_S$
- $2f_S$
- It approaches infinity.

**Correct**

This case involves what is called a sonic boom. The listener will hear no sound ($f_L = 0$) until the sonic boom reaches him or her (just as the source passes by). At that instant, the frequency will be infinite. There is no time between the passing waves--they are literally right on top of each other. That's a lot of energy to pass by the listener at once, which explains why a sonic boom is so loud.

## The Doppler Effect on a Train

A train is traveling at 30.0 $m/s$ relative to the ground in still air. The frequency of the note emitted by the train whistle is 262 $Hz$.

The speed of sound in air should be taken as 344 $m/s$.

### Part A

What frequency $f_{approach}$ is heard by a passenger on a train moving at a speed of 18.0 $m/s$ relative to the ground in a direction opposite to the first train and approaching it?

**Express your answer in hertz.**

**Hint 1.** How to approach the problem

The listener is in motion with respect to the source of sound; therefore, you need to consider the Doppler effect. Moreover, you also need to take into account that the source of sound is moving. If you have a formula that gives the frequency shift when both source and listener are moving, you can apply it directly.

If you only have formulas for the Doppler shift when either the source or listener is moving but not both, you will need to calculate the frequency shift in two steps. First, consider a point somewhere between the two trains and compute the frequency of the train whistle that would be heard by a stationary listener at that point. Then consider that point to be the (stationary) *source* of the sound that is observed by the passenger moving in the second train.

**Hint 2.** Doppler shift equations for moving source or observer

When a source of sound with frequency $f_0$ moves at speed $v_{\rm S}$ with respect to a stationary observer, the observer will hear a sound of frequency $f$ given by

$$f = \frac{f_0}{1 \pm v_{\rm S}/v}.$$

When a source of sound with frequency $f_0$ is stationary with respect to an observer moving with speed $v_{\rm L}$, the observer will hear a sound of frequency $f$ given by

$$f = (1 \pm v_{\rm L}/v) f_0.$$

In both cases, $v$ is the speed of sound and the sign to use depends on whether the source is moving toward or away from the observer.

**Hint 3.** Doppler equations when both the source and the listener are in motion

If $f_{\rm S}$ is the frequency of a sound wave emitted by a source in motion at speed $v_{\rm S}$, the frequency $f_{\rm L}$ of the sound wave heard by a listener in motion at speed $v_{\rm L}$ is given by

$$f_{\rm L} = \frac{v \pm v_{\rm L}}{v \pm v_{\rm S}} f_{\rm S},$$

where $v$ is the speed of sound.

**Hint 4.** Determine the appropriate signs

In the Doppler equation for a moving source and a moving observer,

$$f_L = \frac{v \pm v_L}{v \pm v_S} f_S,$$

where $v$ is the speed of sound, which signs belong in the numerator and denominator if the source and the observer are both moving toward each other? Recall that speed and frequency are both scalar quantities.

**Hint 1.** Qualitative understanding of the Doppler shift

If the source and listener are approaching each other, the frequency observed will be higher than the frequency emitted. Similarly, if the the source and listener are receding from each other, the frequency observed will be lower than the frequency emitted.

ANSWER:

- A minus sign in the numerator and a minus sign in the denominator.
- A plus sign in the numerator and a plus sign in the denominator.
- (selected) A plus sign in the numerator and a minus sign in the denominator.
- A minus sign in the numerator and a plus sign in the denominator.

ANSWER:

$f_{approach}$ = 302 $\mathrm{Hz}$

**Correct**

---

## Part B

What frequency $f_{recede}$ is heard by a passenger on a train moving at a speed of 18.0 $\mathrm{m/s}$ relative to the ground in a direction opposite to the first train and receding from it?

**Express your answer in hertz.**

### **Hint 1.** How to approach the problem

The listener is in motion with respect to the source of sound; therefore, you need to consider the Doppler effect. Moreover, you also need to take into account that the source of sound is moving. If you have a formula that gives the frequency shift when both source and listener are moving, you can apply it directly.

If you only have formulas for the Doppler shift when either the source or listener is moving but not both, you will need to calculate the frequency shift in two steps. First, consider a point somewhere between the two trains and compute the frequency of the train whistle that would be heard by a stationary listener at that point. Then consider that point to be the (stationary) *source* of the sound that is observed by the passenger moving in the second train.

### **Hint 2.** Doppler shift equations for moving source or observer

When a source of sound with frequency $f_0$ moves at speed $v_{\rm S}$ with respect to a stationary observer, the observer will hear a sound of frequency $f$, given by

$$f = \frac{f_0}{1 \pm v_{\rm S}/v}.$$

When a source of sound with frequency $f_0$ is stationary with respect to an observer moving with speed $v_{\rm L}$, the observer will hear a sound of frequency $f$ given by

$$f = (1 \pm v_{\rm L}/v)f_0.$$

In both cases, $v$ is the speed of sound and the sign to use depends on whether the source is moving toward or away from the observer.

### **Hint 3.** Doppler equations when both the source and the listener are in motion

If $f_{\rm S}$ is the frequency of a sound wave emitted by a source in motion at speed $v_{\rm S}$, the frequency $f_{\rm L}$ of the sound wave heard by a listener in motion at speed $v_{\rm L}$ is given by

$$f_{\rm L} = \frac{v \pm v_{\rm L}}{v \pm v_{\rm S}} f_{\rm S},$$

where $v$ is the speed of sound.

**Hint 4.** Determine the appropriate signs

In the Doppler equation for a moving source and a moving observer,

$$f_{\rm L} = \frac{v \pm v_{\rm L}}{v \pm v_{\rm S}} f_{\rm S},$$

where $v$ is the speed of sound, which signs belong in the numerator and denominator if the source and the observer are both moving away from each other? Recall that speed and frequency are both scalar quantities.

**Hint 1.** Qualitative understanding of the Doppler shift

If the source and listener are approaching each other, the frequency observed will be higher than the frequency emitted. Similarly, if the the source and listener are receding from each other, the frequency observed will be lower than the frequency emitted.

ANSWER:

- A minus sign in the numerator and a minus sign in the denominator.
- A plus sign in the numerator and a plus sign in the denominator.
- A plus sign in the numerator and a minus sign in the denominator.
- A minus sign in the numerator and a plus sign in the denominator.

ANSWER:

$f_{\rm recede}$ = 228 $\rm Hz$

**Correct**

## Score Summary:

Your score on this assignment is 83.4%.
You received 8.34 out of a possible total of 10 points.