PHYSICS 2204
Unit 4: Waves
Worksheet #8: Doppler Effect For Sound And Sonic Booms

Student Name: _____

Doppler effect When wave energy like sound or electromagnetic waves travels from two objects, the wavelength can seem to be changed if one or both of them are moving.

The Doppler effect causes the received frequency of a source (how it is perceived when it gets to its destination) to differ from the sent frequency if there is motion that is increasing or decreasing the distance between the source and the receiver. This effect is readily observable as variation in the pitch of sound between a moving source and a stationary observer.

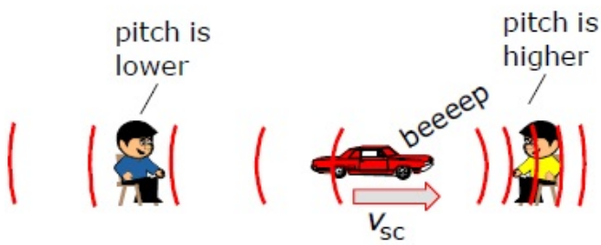
The Doppler effect may occur in all types of waves however we are most familiar with sound waves. Recall an instance in which a police car was traveling towards you on the highway. As the car approached with its siren blasting, the pitch of the siren sound was high; and then suddenly after the car passed by, the pitch of the siren sound was low.

It is important to remember that the source of sound always emits the same frequency.

The Doppler Effect is an apparent change of frequency due to the relative motion between an object listening to a sound and the source of the sound itself. The change of frequency depends on whether or not the listener is moving toward or away from the source or the source is moving toward or away from the listener

Equation 1: Moving Sound Source (Found on formula sheet)

$$f = \frac{f_o v_s}{v_s \pm v_0}$$

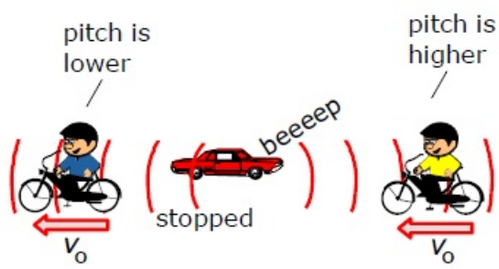


$\mathbf{f_O}$ = the frequency of the sound at the source
f = the observed frequency according to the Doppler Effect
$\mathbf{v_s}$ = Speed of sound
$\mathbf{v_o}$ = the speed of sound

When the source is moving toward the listener it is a (-) and when moving away it is (+).

Equation 2: Moving observer (Not found on formula sheet)

$$f = f_o \frac{(v_s \pm v_o)}{v_s}$$



$\mathbf{f_O}$ = the frequency of the sound at the source
f = the observed frequency according to the Doppler Effect
$\mathbf{v_s}$ = Speed of sound
$\mathbf{v_o}$ = the speed of sound

When the listener is moving toward the sound it is a (+) and when moving away it is (-).

Example 1:

A car passes and moves away from you at 110 km/hr as you stand on the side of the highway in 28º C weather. The driver gives a long beep on the horn. If the horn makes a 450 Hz sound, what frequency do you hear?

Example 2:

A car is approaching you in in 25o C weather in a 100 km/hr zone. The driver gives a long beep on the horn, which you know from the specifications to be a 450 Hz sound. However, you measure the sound to have a 475 Hz pitch. Is the car speeding?

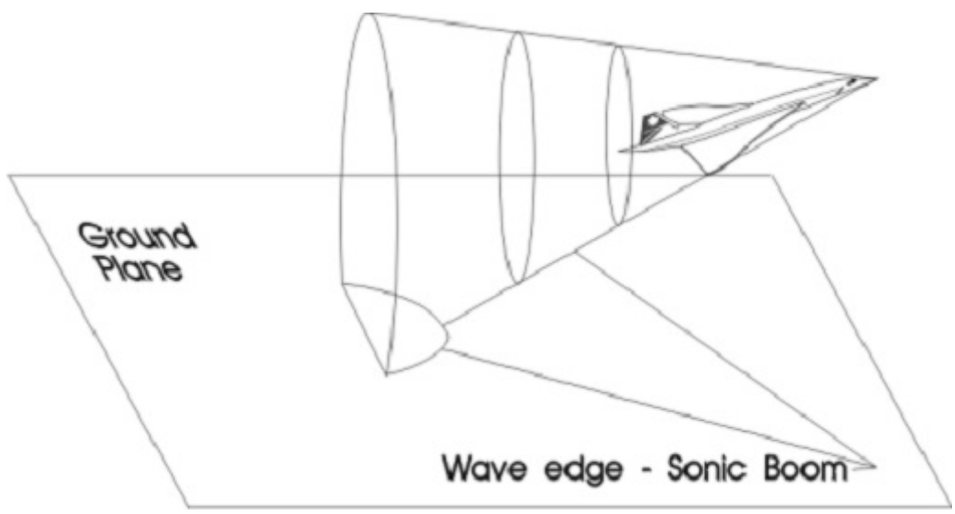
Example 3:

A burglar alarm is wailing with a frequency of 1200 hertz on a 20 OC. What frequency does a cop hear who is driving towards the alarm at a speed of 40.0 m/s?

SONIC BOOM

sonic boom is the thunder-like noise a person on the ground hears when an aircraft or other type of aerospace vehicle flies overhead faster than the speed of sound or supersonic. Air reacts like a fluid to supersonic objects. As objects travel through the air, the air molecules are pushed aside with great force and this forms a shock wave much like a boat creates a bow wave. The bigger and heavier the aircraft, the more air it displaces

For an airplane, 3 dimensions diagram is needed because the plane is in a 3-dimensional "sea of air". Instead of a V-shape wake (like the one behind a speed boat), the plane produces a cone shape wake when it travels faster than the speed of the sound. Because of the constructive interference that takes place in the cone segment, the pressure is very high. When the "shell" of the cone intersects with the ground, the impact of this pressure on our ear drums produces a thunder-like noise that we call a sonic boom.



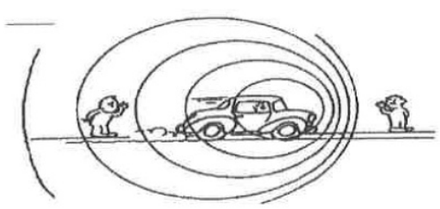
Chuck Yeager was the first person to break the sound barrier when he flew faster than the speed of sound in the X-1 rocket-powered aircraft on October 14, 1947.

PART A: MULTIPLE CHOICE

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

1. When an automobile moves towards a listener, how does the sound of its horn appear to change?

(A) Low pitched
(B) High pitched
(C) Normal
(D) No Change



2. When the automobile moves away from the listener, how does the sound of its horn appear to change?

(A) Low pitched
(B) High pitched
(C) Normal
(D) No Change

3. A trumpet player is standing on a stage playing a single note. Which choice would result in you hearing a higher pitch than the trumpeter?

(A) Cover your ears
(B) Get the trumpeter to point the horn at the sky.
(C) Play the sound much louder through a headphone
✔ (D) Run very fast toward the trumpeter

4. Betty is running at 5.0 m/s toward a whistle, which is stationary. An identical whistle is approaching Bob at 5.0 m/s. Which statement about the pitch of the whistle is correct?

✔ (A) Betty and Bob both hear a pitch which is higher than normal.
(B) Betty and Bob both hear a pitch which is lower than normal.
(C) Betty perceives the pitch to be higher and Bob perceives it to be lower than normal.
(D) Betty perceives the pitch to be lower and Bob perceives it to be higher than normal.

5. An aircraft is moving away from you at half the speed of sound, which, on that day is about 340 m/s. The jet engines make a sound that is primarily about 300 Hz. What is the apparent frequency of the jet engines?

(A) 150 Hz
✔ (B) 200 Hz
(C) 470 Hz
(D) 600 Hz

6. A fast moving car is sounding its horn as it moves by you. What will you observe just as the car passes by you?

(A) The pitch gets lower
(B) The pitch gets higher
(C) The pitch alternates behind high and low, repeatedly
(D) The pitch is unchanged

7. A police car travelling at 30.0 m/s sounds its 525 Hz siren as it approaches a person standing on the side of the road. If the speed of sound is 344 m/s, what frequency is heard by the person?

(A) 483 Hz
(B) 525 Hz
(C) 555 Hz
(D) 575 Hz

8. An ambulance approaches an observer at 31.5 m/s on a day when the speed of sound is 341 m/s. If the frequency heard is 525 Hz, what is the actual frequency of the siren?

(A) 477 Hz
(B) 481 Hz
(C) 573 Hz
(D) 578 Hz

9. High frequency sound waves are directed at an artery. Reflected waves have a different frequency than the incident waves due to the movement of blood cells in an artery. From this difference the speed of blood cells can be determined. This is an application of which wave property?

(A) Diffraction
(B) Doppler Effect
(C) Interference
(D) Refraction

10. What does the Doppler effect produce an apparent changes in?

(A) Amplitude
✔ (B) Frequency
(C) Loudness
(D) Velocity

11. A car horn has a frequency of 400 Hz. The car is moving away from an intersection at 20 m/s. What is the frequency heard by a woman standing at the intersection?

(A) 390 Hz
(B) 400 Hz
(C) 410 Hz
(D) 420 Hz

12. An observer approaches a stationary 1000 Hz sound source at twice the speed of sound. What frequency does the observer hear?

(A) 4,000 Hz
(B) 3,000 Hz
(C) 2,000 Hz
(D) none of these

13. What frequency do you hear if you are traveling at 15 m/s toward a train with a 750 Hz whistle? The train is moving away from you at 25 m/s and the temperature is 15° C.

(A) 668 Hz
(B) 729 Hz
(C) 774 Hz
(D) 845 Hz

14. What is the frequency heard by a stationary observer when a train approaches with a speed of 30 m/s? The frequency of the train horn is 600 Hz and the speed of sound is 340 m/s.

(A) 570 Hz
(B) 630 Hz
(C) 653 Hz
(D) 658 Hz

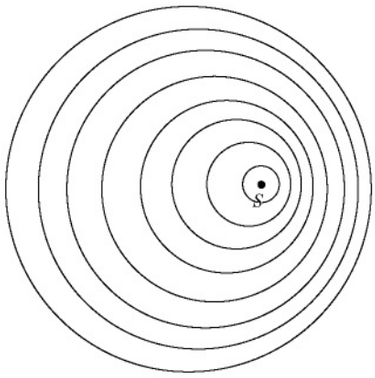
15. A train travelling at a speed of 30.0 m/s. Its whistle generates a sound wave with a frequency of 224 Hz. You are standing besides the tracks as the train moves away from you with its whistle blowing. What frequency do you detect for the pitch of the whistle if the speed of sound in air is 330 m/s?

(A) 185 Hz
✔ (B) 205 Hz
(C) 224 Hz
(D) 246 Hz

16. What is the noise you hear after a high-speed plane flies by?

(A) A sonic boom
(B) Aerodynamics
(C) Supersonic flight
(D) The sound barrier

17. The figure below shows some wavefronts emitted by a source of sound S. This picture can help us to understand



(A) The phenomenon of beats.
(B) Why a sound grows quieter as we move away from the source.
(C) How sonar works.
✔ (D) Why the siren on a police car changes its pitch as it races past us.

18. An observer on the ground will hear a sonic boom from an aeroplane travelling faster than the speed of sound

(A) After the plane has passed by
(B) As the plane is approaching
✔ (C) Only when the plane breaks the sound barrier
(D) When the plane is directly overhead

19. What causes sonic booms?

(A) The powerful engines of high speed aircraft.
(B) The weapons used in fighter jets
✔ (C) The constructive interference of compressional waves produced by objects traveling faster than the speed of sound.
(D) The sounds produced by something going faster than the speed of sound. Because the source of going faster than the speed of sound, all of the energy reaches you at the same time.

20. When do supersonic aircraft produce sonic booms?

✔ (A) At the instant they "break through the sound barrier."
(B) At all times when they are flying either at or greater than the speed of sound.
(C) Only when they are traveling at some multiple of the speed of sound (Mach 1, Mach 2 and Mach 3, etc.)
(D) Only when they are flying at exactly the speed of sound.

PART B: WRITTEN RESPONSE

1. An ambulance siren emits a frequency of 440 Hz. If the air temperature is 22^{O}, calculate the frequency heard by an observer if the ambulance is coming toward him at 26 m/s. **June 2010**

2. A car is moving towards a stationary observer at 15.1 m/s when the driver blows the horn with a frequency of 870 Hz. If the speed of sound is 344 m/s what is the frequency of the sound perceived by the observer? **June 2011**

3. A burglar alarm is wailing with a frequency of 1200 hertz. What frequency does a cop hear who is driving towards the alarm at a speed of 40.0 m/s? **Answer is 1340 Hz**

4. With reference to the above problem, what frequency would the burglar hear, if he was running away from the alarm at a speed of 10 m/s? **Answer is 1170 Hz**

5. A cop cars siren has a frequency of 700. hertz. If you are standing on the sidewalk as the cop car approaches you at a speed of 15.0 m/s, what frequency would you hear? **Answer is 732 Hz**

6. In the previous problem, what frequency would you hear if the cop were driving away from you at a speed of 25 m/s? **Answer is 652 Hz**

7. An alarm clock is dropped off the edge of a tall building. You, standing directly under it, hear a tone of 1350 Hz coming from the clock at the instant it hits the ground (you jumped out of the way at the last moment- whew!) Since you know the building is 25.0 m tall, you can find out what the frequency of the alarm would be if you had just held it in your hands. What would that frequency be? **Answer is 1260 Hz**

8. A siren of frequency of 570 Hz is moving toward a driver in a car at 45 m/s. What is the apparent frequency of the siren as it moves toward the driver and away from the driver?

9. A runner is jogging along the sidewalk when a little baby starts crying at a frequency of 400 Hz. If the running is traveling at 25 m/s, what is the apparent change in frequency he hears as he approaches and passes the baby?

10. A police car is chasing a bad guy down the road. The police car has its siren on which is at a frequency of 800 Hz. If the police car is traveling at 65 m/s and the bad guy is in front of the police car traveling 80 m/s, what frequency does the bad guy hear?

11. A train is approaching a station at 30 m/s when it sounds its 800 Hz whistle. To a person standing on the train platform what will be the perceived frequency of the whistle? **ANSWER IS 877 Hz**

12. The referee is skating down the ice, away from you, at 15 m/s, blowing his whistle. The frequency of the whistle is 1000 Hz. What will you perceive it to be? **Answer is 958 Hz**

13. The engine of a race car produces a sound with a frequency of 350 Hz. The car is moving at 85 m/s.

    a. If the car is coming towards you, what will you perceive its frequency to be? **Answer is 470 Hz**
    b. If the car is moving away from you, what will you perceive its frequency to be?
    c. Suppose that the car approaches you and passes you by. Describe the sound that you hear.

14. What is the frequency heard by a person driving at 15 m/s toward a blowing factory whistle (800. Hz) if the speed of sound is 340.6 m/s? **Answer is 835 Hz**

15. Two fire trucks with sirens on speed towards and away from an observer as shown below.

a) Which truck produces a higher than normal siren frequency? **Answer is left truck**
b) Which truck produces a lower than normal siren frequency? **Answer is right truck**

16. From the previous problem, what frequency would he hear after passing the factory if he continues at the same speed? **Answer is 765 Hz**

17. A car approaching a stationary observer emits 450. Hz from its horn. If the observer detects a frequency of 470. Hz, how fast is the car moving? The speed of sound is 343 m/s. **Answer is 15 m/s**

18. While standing near a railroad crossing, a person hears a distant train horn. According to the train's engineer, the frequency emitted by the horn is 440 Hz. The train is traveling at 20.0 m/s and the speed of sound is 346 m/s.

a) What would be the frequency of the train's horn if the train were at rest? **Answer is 440 Hz**

b) What is the adjusted frequency that reaches the bystander as the train approaches the crossing? **Answer is 467 Hz**

c) What is the adjusted frequency that reaches the bystander once the train has passed the crossing?

Answer is 416 Hz

19. A burglar alarm is wailing with a frequency of 1200. hertz. What frequency does a cop hear who is driving towards the alarm at a speed of 40.0 m/s? The air temperature is 35.0 ºC.

Answer is 1336 Hz

20. With reference to the previous problem, what frequency would the burglar hear, if he was running away from the alarm at a speed of 10 m/s? **Answer is 1166 Hz**

21. A cop car's siren has a frequency of 700. Hz. If you are standing on the sidewalk as the cop car approaches you at a speed of 15.0 m/s, what frequency would you hear? The speed of sound is 343 m/s.

Answer is 732 Hz

22. In the previous problem, what frequency would you hear if the cop were driving away from you at a speed of 25 m/s? **Answer is 652 Hz**

23. An alarm clock is dropped off the edge of a tall building. You, standing directly under it, hear a tone of 1350. Hz coming from the clock at the instant it hits the ground. Since you know the building is 25.0 m tall, you can find out what the frequency of the alarm would be if you had just held it in your hands. What would that frequency be? The speed of sound is 343 m/s. **Answer is 1263 Hz**

24. Two identical cars are driving toward one another and sounding their horns. You're the driver of one of the cars. You measure your car's horn to be sounding at 512 Hz, but you measure the horn of the other car to be sounding at 600. Hz. The speed of sound is 345 m/s. If you are traveling at 26.8 m/s , how fast is the other car traveling? **Answer is 27.7 m/s**