Doppler Effect

Key Concepts

In this lesson, you will be taught how to

- Define Doppler effect
- Predict changes in the observed frequencies as the source and the observer move in relation to each other
- Use the Doppler effect equation to solve problems
- Tell whether the sound is subsonic or supersonic
- Find the Mach number for a moving source of sound, especially jets

Terminology & definitions

- Doppler Effect - the perceived change in the frequency of sound as the source and/or the listener move in relation to each other.
- Mach number - the ratio of the velocity of source to the velocity of sound.

X-planation of key concepts and terminologies

The observed frequency is greater when the source and the listener move towards each other, and is lower when the source and/or the listener move away from each other. The following Doppler equation is used to calculate for the perceived/observed frequency:

$$f_L = \left(\frac{v \pm v_L}{v \pm v_s} \right) f_s$$

When the speed of the source is smaller than the speed of sound, the sound is said to be subsonic. When the speed of the source is greater than the speed of sound, the sound produced, is said to be supersonic. In a situation where the speed of the source equals the speed of sound, a sound barrier is created. In this case, the Mach number equals 1 since it is given by the ratio of the velocity of the source and that of sound in air. A sonic boom will be produced by a moving object if its velocity exceeds the velocity of sound in air, e.g., a jet. In this case, the Mach number is greater than 1.

X-amples

1. A fire engine with its siren on approaches a man standing by the roadside. The siren emits a sound with a frequency of 430 Hz. The speed of the fire engine as it approaches the man is 10 $m \bullet s^{-1}$. Calculate the frequency of the sound heard by the man if the speed of sound in air was 340 $m \bullet s^{-1}$.

2. An ambulance with a siren of frequency 600 Hz is moving towards a group of onlookers. Calculate the frequency of sound heard by the onlookers when the ambulance:

   a.) approaches the onlookers at 80 $km \bullet h^{-1}$.
   b.) moves away from the onlookers at 90 $km \bullet h^{-1}$.

3. An ambulance with its siren, on moves towards Mpho who is standing at a traffic light. If the frequency of the ambulance siren is 240 Hz, determine the frequency of the siren heard by Mpho if the ambulance is approaching at speed of 20 $m \cdot s^{-1}$. (Use 344 $m \cdot s^{-1}$for the speed of sound in air).

4. The sound waves produced by a jet has a frequency of 1300 Hz. If the speed of soumd in air is 344 $m.s^{-1}$

   a.) Calculate the frequency heard by a crowd of people standing on the ground when the jet is approaching at a velocity of 494 $km.h^{-1}$.

   b.) Calculate the frequency heard by the people on the ground when the jet moves away at the same velocity.

   c.) What frequency would be heard by the people on the ground when the jet is directly above them?

5. An ambulance traveling down a road at constant speed emits sound waves from its siren. A lady stands on the side of the road with a detector which registers sound waves at a frequency of 445 Hz as the ambulance approaches her. After passing her at the same constant speed, sound waves of frequency 380 Hz are registered. Assume that the speed of sound in air is 343 $m \bullet s^{-1}$.

   5.1 Name the phenomenon that describes the change in the frequency observed by the lady.

   5.2 Calculate:

   a.) the speed at which the ambulance is moving.

   b.) the frequency at which the siren emits the sound waves.

X-ercise

1. The sketch below shows a stationary ambulance.

Stationary ambulance

Car passing at constant speed

The siren of the ambulance emits sound waves of frequency 700 Hz. The driver of a car approaching the ambulance and passing it at constant speed, observes the frequency of the emitted sound waves to change by 80 Hz. Take the speed of sound in air as 340 $m \cdot s^{-1}$. Calculate the speed at which the car passes the ambulance.

2. Dolphins use ultrasound to scan their environment. When a dolphin is 100 m from a rock, it emits ultrasound waves of frequency 250 kHz whilst swimming at 20 $m \cdot s^{-1}$ towards the rock. Assume that the speed of sound in water is 1 500 $m \cdot s^{-1}$.

   2.1 Calculate the frequency of the sound waves detected by a detector on the rock.

   2.2 When the dolphin is 50m away from the rock, another ultrasound wave of 250kHz is emitted. How will the frequency of the detected sound waves compare with the answer calculated in 2.1? Write down higher, lower, or remains the same. Explain your answer.

Answers

1. $v_L = 19{,}43\ m \cdot s^{-1}$

2.1 $f_L = = 253{,}38 \times 10^3$ Hz

2.2 Remains the same. The detected frequency is independent of the distance between the source and the observer.