

A Train Moves Away From A Station At 50 M/s. The Train Blows Its Whistle That Has A Frequency Of 520

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Understanding the physics behind sound waves and the Doppler effect is crucial when analyzing scenarios involving moving sources of sound, such as a train moving away from a station while blowing its whistle. In this article, we delve into the principles governing the behavior of sound waves in this context, exploring how the motion of the train affects the perceived frequency at different observing points. Whether for academic purposes, engineering applications, or general curiosity, grasping these concepts provides valuable insights into wave phenomena and their real-world implications.

Introduction to Sound Waves and the Doppler Effect

What Are Sound Waves?

Sound waves are longitudinal waves that propagate through a medium—such as air, water, or solids—by vibrating particles. These waves are characterized by their frequency, wavelength, speed, and amplitude. In air, the speed of sound at room temperature ($\sim 20^{\circ}\text{C}$) is approximately 343 meters per second (m/s).

Understanding the Doppler Effect

The Doppler effect refers to the change in frequency or wavelength of a wave in relation to an observer moving relative to the source of the wave. It is most noticeable with sound waves, especially in scenarios involving moving vehicles or sound-emitting objects.

Key points about the Doppler effect:

- When the source approaches the observer, the observed frequency increases.
- When the source recedes from the observer, the observed frequency decreases.
- The effect depends on the relative velocity between source and observer and the speed of sound in the medium.

Scenario Overview: A Moving Train and Its Whistle

In our case:

- The train is moving away from the station at a velocity $(v_s = 50, \text{m/s})$.
- The train's whistle has an emitted frequency $(f_s = 520, \text{Hz})$.
- The speed of sound in air is assumed $(v = 343, \text{m/s})$.

This setup raises several interesting questions:

- What is the frequency of the whistle as perceived by an observer standing on the station (stationary observer)?
- How does the train's motion influence the perceived sound?
- What are the implications for safety and communication?

Calculating the Perceived Frequency for a Stationary Observer

Using the Doppler Effect Formula

For a source moving away from a stationary observer, the observed frequency (f_o) is given by:

$$f_o = \frac{f_s}{1 + \frac{v_s}{v}}$$

where:

- (f_s) = emitted frequency of the source (520 Hz)
- (v_s) = velocity of the source relative to the medium (50 m/s, positive when moving away)
- (v) = speed of sound in air (343 m/s)

Note: Since the train is moving away, the denominator includes $(1 + v_s/v)$.

Calculation Steps

Plugging in the values:

$$f_o = \frac{520}{1 + \frac{50}{343}} = \frac{520}{1 + 0.1458} = \frac{520}{1.1458}$$

$$f_o \approx 520 / 1.1458 \approx 453.8, \text{Hz}$$

Result:

The station observer perceives the whistle at approximately 454 Hz, which is lower than the emitted frequency due to the train moving away.

Implications of the Doppler Effect in This Scenario

Perceived Frequency and Its Significance

The reduction in perceived frequency illustrates how motion affects sound perception:

- The farther the source moves away, the lower the frequency perceived.
- Conversely, approaching sources increase perceived frequency, causing a higher pitch.

Real-World Applications

Understanding these effects is vital in:

- Railway safety communication systems
- Designing warning signals that remain audible regardless of train speed
- Acoustic engineering and noise pollution studies

Additional Considerations in the Scenario

Frequency When the Train Approaches the Station

If the train were approaching the station at the same speed, the observed frequency would be:

$$\begin{aligned} f_o &= \frac{f_s}{1 - \frac{v_s}{v}} = \frac{520}{1 - 0.1458} = \frac{520}{0.8542} \approx 608.7, \\ &\text{Hz} \end{aligned}$$

This higher perceived frequency could be critical for alert mechanisms.

Effects of Observer Movement

While this scenario assumes a stationary observer, if the observer moves towards or away from the source, the perceived frequency further changes, following similar formulas.

Understanding the Physics Through Wavefronts and Doppler Shift

Wavefronts Behind and Ahead of Moving Source

- When moving away, wavefronts behind the train are spaced farther apart, resulting in a lower frequency.
- When approaching, wavefronts are compressed, leading to a higher perceived frequency.

Graphical Representation

Visualizing the wavefronts helps:

- To comprehend how the source's motion affects wave propagation.
- To understand why perceived frequencies differ based on observer position and source movement.

Practical Examples and Calculations

Example 1: Effect of Increasing Train Speed

Suppose the train accelerates to 80 m/s:

$$f_o = \frac{520}{1 + \frac{80}{343}} = \frac{520}{1 + 0.2335} = \frac{520}{1.2335} \approx 421.5, \text{ Hz}$$

Observation:

The perceived frequency further decreases as the train speeds up, emphasizing the importance of understanding Doppler shifts in high-speed rail systems.

Example 2: Effect of Different Ambient Conditions

Variations in air temperature and humidity can slightly alter the speed of sound, affecting calculations. For precise applications, adjustments should be made accordingly.

Real-World Applications of Doppler Effect in Railway

Systems

Safety and Communication

- Emergency sirens and alarms are designed considering Doppler shifts to ensure audibility.
- Signal systems may account for Doppler effects to provide accurate communication.

Navigation and Monitoring

- Doppler radar is used to measure train speeds and monitor traffic flow.
- Acoustic sensors can detect deviations in expected sound frequencies, indicating potential issues.

Conclusion

In scenarios where a train moves away from a station at 50 m/s while blowing a whistle at 520 Hz, the Doppler effect causes the perceived frequency at the station to drop to approximately 454 Hz. Understanding this phenomenon is essential for designing effective safety systems, communication protocols, and acoustic engineering solutions in railway operations. The principles governing sound wave behavior and the Doppler effect extend beyond trains, playing a crucial role in various fields such as meteorology, astronomy, and medical imaging. Mastery of these concepts enables engineers, scientists, and safety officials to optimize systems that rely on sound wave transmission and perception, ensuring safety, efficiency, and clarity in a world of moving sources and observers.

Summary of Key Points:

- The Doppler effect causes perceived frequency changes based on source motion.
- Moving away from a stationary observer reduces perceived frequency.
- Calculations demonstrate how velocity influences perceived sound.
- Real-world applications include safety systems, radar technologies, and acoustics.

Remember:

Always consider the medium's sound speed and relative motion when analyzing wave phenomena to ensure accurate interpretations and system designs.

Frequently Asked Questions

What is the significance of the train blowing its whistle at a frequency of 520 Hz?

The 520 Hz frequency indicates the pitch of the whistle, which can be used to analyze the Doppler

effect as the train moves away from the observer.

How does the Doppler effect influence the perceived frequency of the train's whistle as it moves away?

As the train moves away, the observer perceives a lower frequency than 520 Hz due to the Doppler effect, caused by the relative motion between the train and the observer.

What is the apparent frequency of the whistle when the train is moving away at 50 m/s?

The apparent frequency can be calculated using the Doppler formula: $f' = f (v + v_o) / (v + v_s)$. Assuming the observer is stationary and $v = 340$ m/s, the perceived frequency is approximately 464 Hz.

If the train is moving at 50 m/s away from a stationary observer, what is the Doppler-shifted frequency of the whistle?

Using the Doppler formula, the perceived frequency is approximately 464 Hz, indicating a lower pitch than the original 520 Hz.

Why does the frequency of the train's whistle decrease as it moves away from the observer?

The frequency decreases due to the Doppler effect, where the relative motion causes the sound waves to stretch out, resulting in a lower perceived pitch.

What factors affect the magnitude of the Doppler shift in this scenario?

The factors include the speed of the train (50 m/s), the original frequency (520 Hz), and the speed of sound in air (approximately 340 m/s).

How can the Doppler effect be used to determine the speed of a moving train?

By measuring the change in perceived frequency of the whistle and applying the Doppler formula, the train's speed can be calculated if the original frequency and the speed of sound are known.

What assumptions are made when calculating the perceived frequency of the train's whistle?

Assumptions include a stationary observer, constant train speed, no other environmental effects on sound propagation, and a uniform speed of sound in air.

If the train were approaching the station instead of moving away, how would the perceived frequency change?

The perceived frequency would increase above 520 Hz due to the Doppler effect, resulting in a higher pitch as the train approaches.

What practical applications does understanding the Doppler effect in train whistles have?

It helps in designing warning systems, estimating train speeds, and improving safety measures by accurately interpreting sound signals in moving vehicles.

Additional Resources

A train moves away from a station at 50 m/s. The train blows its whistle that has a frequency of 520 Hz. This scenario encapsulates multiple fundamental principles of physics, particularly the Doppler effect, wave propagation, and sound perception. Analyzing this situation provides insight into how motion influences sound waves and how observers perceive changes in frequency and pitch. This article aims to dissect the scenario comprehensively, exploring the physics behind it, the implications, and practical applications.

Understanding the Scenario: Key Components and Initial Context

1. The Setting

The scenario involves a train moving away from a stationary observer positioned at the station. The train is traveling at a significant velocity of 50 meters per second (m/s), which is roughly 180 kilometers per hour or approximately 112 miles per hour. Such a speed is typical for high-speed trains or express services, emphasizing the relevance of physics in real-world transportation.

2. The Train's Whistle

The train's whistle emits a sound wave with a frequency of 520 Hz in the train's frame of reference—meaning, if the train were stationary relative to the observer, the sound would be perceived at 520 Hz. The whistle's frequency is an intrinsic property determined by the whistle's design; however, the perceived frequency by an observer depends on the relative motion between the source and the observer.

3. The Relative Motion

The key aspect here is that the source of the sound (the train's whistle) is moving away from the observer. This relative motion causes a phenomenon known as the Doppler effect, which results in the perceived frequency being different from the emitted frequency.

The Physics of Sound and the Doppler Effect

1. Fundamentals of Sound Waves

Sound waves are longitudinal waves propagating through a medium, such as air. Their key properties include:

- Frequency (f): Number of oscillations per second, measured in Hertz (Hz).
- Wavelength (λ): Distance between successive crests of the wave.
- Speed of sound (v): The rate at which sound propagates through the medium; approximately 343 m/s in air at room temperature.

The relationship between these is given by:

$$v = f \times \lambda$$

2. The Doppler Effect Explained

The Doppler effect describes how the observed frequency (f') changes when the source and observer are in relative motion. For sound waves, the observer perceives a different frequency depending on whether the source is moving toward or away from them.

When the source moves away from a stationary observer, the observed frequency (f') is decreased, and is given by:

$$f' = f \times \frac{v}{v + v_s}$$

Where:

- (v) = speed of sound in the medium (air, in this case, approximately 343 m/s).
- (v_s) = speed of the source relative to the medium. Positive if moving away from the observer.

Conversely, if the source approaches the observer:

$$f' = f \times \frac{v}{v - v_s}$$

3. Conditions of the Scenario

In the given scenario:

- The train (source) moves away at $(v_s = 50, \text{m/s})$.
- The observer is stationary relative to the ground, at the station.
- The speed of sound in air is approximately $(v = 343, \text{m/s})$.

Applying these values will help determine the perceived frequency.

Calculating the Perceived Frequency

1. Applying the Doppler Effect Formula

Since the train is moving away from the observer, the perceived frequency (f') is:

$$f' = f \times \frac{v}{v + v_s}$$

Substituting the known values:

$$f' = 520, \text{Hz} \times \frac{343, \text{m/s}}{343, \text{m/s} + 50, \text{m/s}}$$

$$f' = 520, \text{Hz} \times \frac{343}{393}$$

Calculating:

$$\frac{343}{393} \approx 0.872$$

$$f' \approx 520 \times 0.872 \approx 453, \text{Hz}$$

Result: The observer perceives the train's whistle at approximately 453 Hz, which is lower than the emitted frequency.

2. Interpretation of the Result

- The decrease from 520 Hz to approximately 453 Hz illustrates the classic pitch drop when the source recedes.
- The difference (about 67 Hz) might seem small but is significant enough for the human ear to perceive as a lower pitch.

Implications and Real-World Applications

1. Significance in Transportation and Safety

- Auditory Cues: Train horns and whistles serve as critical safety signals. Understanding how their perceived pitch changes with motion can inform both train operators and pedestrians about the train's approach or retreat.
- Design Considerations: Engineers take into account the Doppler effect when designing warning signals so they remain perceptible over various speeds and distances.

2. Doppler Effect in Other Domains

This phenomenon isn't limited to sound waves. It is central to various fields:

- Astronomy: Measuring the redshift or blueshift of light from celestial objects to determine their motion relative to Earth.
- Radar and Sonar: Used in speed detection and underwater navigation.
- Medical Imaging: Doppler ultrasound assesses blood flow velocity.

3. Limitations and Real-World Variability

While the calculations assume ideal conditions—such as constant speed and no environmental interference—real-world factors can influence perception:

- Wind and atmospheric conditions can alter sound propagation.
- The observer's hearing sensitivity varies.
- The train might accelerate or decelerate, affecting the perceived frequency dynamically.

The Broader Physics Context: Beyond the Basic Doppler Effect

1. Effects at Different Velocities

- As the train's velocity approaches the speed of sound, relativistic effects become significant, leading to phenomena such as sound barrier effects and shock waves.
- Although 50 m/s is well below the speed of sound, understanding these effects is critical in aeronautics and high-speed rail design.

2. The Source and Observer Dynamics

- The analysis changes if the observer is moving while the source remains stationary or both are moving.
- For example, if the observer walks toward the train, the perceived frequency increases, demonstrating the symmetry of the Doppler effect.

3. Frequency Shift and Pitch Perception

- The human ear perceives frequency changes as pitch alterations. The drop from 520 Hz to 453 Hz translates into a noticeable pitch decrease, affecting auditory perception.

Conclusion: The Interplay of Motion and Sound

This scenario vividly demonstrates the fundamental principles of wave physics and the Doppler effect. When a train moves away from a station at 50 m/s, the sound it emits at 520 Hz is perceived at a lower frequency, approximately 453 Hz, thanks to the relative motion between source and observer. Such understanding is essential not only in theoretical physics but also in practical applications spanning transportation safety, astronomy, medical diagnostics, and communication systems.

The Doppler effect exemplifies how motion influences wave phenomena and shapes our perception of the world. From the deep rumble of a receding train to the cosmic redshift observed in distant galaxies, the principles remain consistent, emphasizing the universality of physics. Recognizing these effects enriches our comprehension of the natural world and enhances technological innovations that rely on wave propagation and motion detection.

In essence, this analysis underscores the importance of physics in everyday life, illustrating how a simple scenario involving a moving train and its whistle encapsulates complex principles that resonate across various scientific and engineering disciplines.

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