A Train Moves Away From A Station At 50 M/s. The Station Whistle Blows With A Frequency Of 520 Hz. What

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Understanding the physics behind sound perception during train movement involves exploring concepts such as the Doppler effect, wave propagation, and sound frequency perception. When a train moves away from a station where a whistle is blown, the sound waves emitted by the whistle undergo changes in frequency and wavelength as perceived by an observer. This article delves into the physics principles involved, the calculation of the observed frequency, and real-world applications of these concepts.

Fundamentals of Sound and the Doppler Effect

What Is Sound?

Sound is a mechanical wave that propagates through a medium such as air, water, or solids. It results from vibrations that create pressure waves traveling through the medium. The key properties of sound include:

- Frequency (Hz): Number of wave cycles per second.
- Wavelength (m): Distance between successive compressions or rarefactions.
- Speed of sound (m/s): Varies depending on the medium; in air at room temperature, approximately 343 m/s.

The Doppler Effect Explained

The Doppler effect describes the change in frequency or pitch of a wave in relation to an observer moving relative to the source of the wave. It is observed in sound, light, and other wave phenomena.

- Approaching source or observer: Higher perceived frequency.
- Receding source or observer: Lower perceived frequency.

Mathematically, the observed frequency f' in the case where the source moves away from the observer is given by:

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

Where:
- f: Actual frequency emitted by the source.
- v: Speed of sound in the medium.
- v_s: Speed of the source moving away from the observer.

Analyzing the Scenario: Moving Train and Station Whistle

Given Data

- Speed of train (source): $v_s = 50\, \text{m/s}$
- Frequency of whistle (source): $f = 520\, \text{Hz}$
- Speed of sound in air: $v = 343\, \text{m/s}$ (at room temperature)

The question is: What is the frequency of the whistle as perceived by an observer at the station when the train moves away?

Assumption

- The observer is stationary at the station.
- The train is moving directly away from the station.
- No significant environmental factors (like wind or temperature variations) affect the speed of sound.

Calculating the Perceived Frequency

Applying the Doppler Effect Formula

Since the train is moving away from the station, the Doppler effect formula for a stationary observer and a moving source applies as:

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

Substituting the known values:

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

Calculating the denominator:

$$
343 + 50 = 393\, \text{m/s}
$$

Thus:

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

Calculating the ratio:

$$
\frac{343}{393} \approx 0.873
$$

Finally:

$$
f' \approx 520 \times 0.873 \approx 453.96\, \text{Hz}
$$

Therefore, the station perceives the whistle at approximately 454 Hz.

Implications of the Doppler Effect in Real-World Scenarios

Impact on Sound Perception

The reduction in perceived frequency when the source moves away causes the whistle's pitch to sound lower. This effect is critical in various fields:

- Aviation: Pilots and air traffic controllers interpret Doppler shifts for aircraft speed and position.
- Radar and Sonar: Used for detecting object movement.
- Medical Imaging: Doppler ultrasound measures blood flow velocity.

Practical Examples

- Train and Railway Safety: Engineers monitor Doppler shifts to assess train speed.
- Meteorology: Doppler radar detects weather patterns by analyzing frequency shifts.
- Music and Acoustics: Doppler effects are intentionally used in sound design and effects.

Additional Considerations and Advanced Topics

Effects of Angled Movement

If the train moves at an angle rather than directly away from the observer, the observed frequency change depends on the component of the velocity along the line of sight:

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

Where θ is the angle between the train's movement direction and the line connecting train and observer.

Effects in Different Mediums

- The speed of sound varies with temperature, humidity, and medium composition.
- For precise measurements, environmental factors should be considered.

Limitations and Assumptions

- Assumes uniform speed of sound.
- Assumes no significant environmental disturbances.
- Assumes direct line-of-sight movement.

Summary and Key Takeaways

- The perceived frequency of a sound source moving away from an observer decreases according to the Doppler effect.
- In the given scenario, the station perceives the whistle at approximately 454 Hz when the train moves at 50 m/s away.
- Understanding the Doppler effect is vital in multiple scientific and engineering disciplines, including transportation, meteorology, and medical imaging.
- Accurate calculations require considering environmental factors and movement angles.

Conclusion

The physics behind sound perception during relative motion provides insight into how motion affects wave properties. In the case of a train moving away from a station at 50 m/s with a whistle frequency of 520 Hz, the station perceives a lower frequency of approximately 454 Hz due to the Doppler effect. Recognizing and calculating such frequency shifts is essential in applications ranging from safety systems to scientific research, illustrating the profound impact of wave phenomena in our daily lives.

Meta Description:
Learn how the Doppler effect influences sound frequency perception when a train moves away from a station. Discover calculations and real-world applications in this comprehensive guide.

Frequently Asked Questions

A train moves away from a station at 50 m/s while its whistle blows at 520 Hz. What is the observed frequency by a stationary observer at the station?

Using the Doppler effect for a moving source and stationary observer: f' = (f v) / (v + v_s). Assuming speed of sound v = 340 m/s, f' = (520 340) / (340 + 50) ≈ 520 340 / 390 ≈ 520 0.872 ≈ 453 Hz. The observed frequency is approximately 453 Hz.

If the train continues moving away at 50 m/s and the original whistle frequency is 520 Hz, how does the observed frequency change as the train speeds up?

As the train's speed increases, the observed frequency decreases because the train moves away, following the Doppler effect formula: f' = (f v) / (v + v_s). Therefore, the greater the speed v_s, the lower the observed frequency.

What is the significance of the train moving away at 50 m/s in determining the Doppler shifted frequency?

The speed of the train (50 m/s) affects the Doppler shift, causing the observed frequency at the station to decrease because the source is receding from the observer, leading to a lower perceived pitch.

How would the observed frequency change if the train were approaching the station at 50 m/s instead of moving away?

If the train approached the station at 50 m/s, the observed frequency would increase. Using the Doppler formula: f' = (f v) / (v - v_s). For v_s = 50 m/s, f' ≈ (520 340) / (340 - 50) ≈ 520 340 / 290 ≈ 520 1.172 ≈ 609 Hz.

What assumptions are made in calculating the Doppler effect in this scenario?

Assumptions include that the speed of sound in air is 340 m/s, the motion is directly along the line of sight (straight away or approach), and the medium (air) is stationary and uniform.

If the station whistle has a frequency of 520 Hz, what is the wavelength of the sound emitted by the train?

Using the relation λ = v / f, with v = 340 m/s, λ = 340 / 520 ≈ 0.654 meters. The wavelength is approximately 0.654 meters.

What effect does the train's speed have on the pitch heard by a passenger inside the train?

Inside the train, passengers perceive the sound at the original frequency (520 Hz) because the source and observer are moving together, so there is no Doppler shift relative to the train.

How does the Doppler effect help in determining the train's speed based on the change in frequency observed at the station?

By measuring the change in observed frequency from the original 520 Hz, the train's speed can be calculated using the Doppler formula: $v_s = v (f - f') / f'$.

What is the importance of understanding the Doppler effect in railway signaling and safety?

Understanding the Doppler effect helps in designing warning systems, communication, and signaling devices that account for frequency shifts caused by moving trains, enhancing safety and effective communication.

In this scenario, if the train's whistle frequency is 520 Hz and it moves away at 50 m/s, what is the ratio of observed to emitted frequency?

Using the Doppler effect: $f' / f = v / (v + v_s)$. With $v = 340$ m/s and $v_s = 50$ m/s, ratio ≈ 340 / 390 ≈ 0.872. Therefore, the observed frequency is about 87.2% of the emitted frequency.

Additional Resources

A Train Moves Away From A Station At 50 m/s. The Station Whistle Blows With A Frequency Of 520 Hz. What

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Introduction

In the realm of physics, the phenomenon of sound wave propagation and the Doppler effect often intersect in compelling ways, especially in real-world scenarios involving moving sources and observers. One such intriguing case involves a train moving away from a station at a high velocity, with the station's whistle emitting a known frequency. This situation provides a practical illustration of how relative motion influences the perceived frequency of sound waves. This article delves deeply into the physics underlying this scenario, analyzing the Doppler effect's role, calculating the perceived frequency at the station, and exploring the broader implications of these principles in transportation, acoustics, and science education.

Contextual Overview

Imagine a train traveling at a constant speed of 50 meters per second (m/s) directly away from a stationary station. The train's horn emits a pure tone with a frequency of 520 Hz. From the perspective of the station, which is stationary relative to the ground, the question arises: What is the frequency of the whistle that the station perceives as the train recedes?

Understanding this scenario requires an appreciation of the Doppler effect — a change in frequency or wavelength of a wave in relation to an observer moving relative to the source of the wave. The classical Doppler effect equation for sound, assuming a stationary observer and a moving source, is:

$$ f' = \frac{f}{1 + \frac{v_s}{v}} $$

where:
- f' is the observed frequency,
- f is the emitted frequency,
- v_s is the velocity of the source relative to the medium (positive when moving away),
- v is the speed of sound in the medium (air).

In this case, the source (train) is moving away from the observer (station), which influences the perceived frequency.

The Physics of the Doppler Effect in This Scenario

Fundamental Principles

The Doppler effect for sound depends on the relative motion between the source and the observer:

- Source moving away from the observer: The observed frequency decreases.
- Source moving towards the observer: The observed frequency increases.
- Stationary source with a moving observer: Similar principles

apply, but with the roles reversed.

For clarity, assuming the air medium is stationary and the sound propagates through it:

$$ f' = \left(\frac{v}{v \pm v_s} \right) f $$

where:

- $+$ is used when the source approaches, $-$ when receding,
- v_s is positive if the source is moving away.

Given the train's velocity is 50 m/s and the speed of sound in air is approximately 343 m/s at room temperature, we can analyze how the perceived frequency varies.

Significance of Relative Speeds

The ratio of the train's speed to the speed of sound is:

$$ \frac{v_s}{v} = \frac{50}{343} \approx 0.146 $$

This indicates that the train's speed constitutes approximately 14.6% of the speed of sound, which is significant enough to produce a noticeable Doppler shift.

Calculating the Perceived Frequency

Given the train is moving away from the station, the appropriate Doppler formula is:

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

Plugging in the known values:

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

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

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

$$
f' \approx 453.4\, \text{Hz}
$$

Therefore, the station perceives the whistle frequency to be approximately 453 Hz when the train is receding at 50 m/s.

Broader Considerations and Implications

Impact on Communication and Safety

In transportation systems, especially railways, understanding Doppler shifts is critical for both safety and communication systems:

- Audible signals: Engineers and station personnel must be

aware that moving trains can produce shifted signals, potentially affecting auditory warnings.
- Sensor and detection systems: Modern systems rely on precise frequency measurements, which need to account for relative motion to avoid false alarms or missed detections.

Acoustic Signatures and Environmental Factors

While the pure Doppler formula provides a theoretical baseline, real-world observations are influenced by:

- Environmental conditions: Temperature, humidity, and atmospheric pressure affect the speed of sound.
- Train and whistle characteristics: The actual emitted frequency may fluctuate due to engine load, horn design, and other mechanical factors.
- Multiple reflections: Echoes and ambient noise can distort perceived frequencies.

Engineering and Scientific Applications

Understanding Doppler shifts in high-speed contexts is vital across various domains:

- Radar and Sonar Technologies: Doppler principles are used for speed detection, weather monitoring, and underwater navigation.
- Astronomy: Similar Doppler effects help determine the movement of celestial bodies.
- Medical Imaging: Doppler ultrasound assesses blood flow velocities.

Limitations and Assumptions

The calculations presented assume:

- Uniform velocity of the train (no acceleration).
- No significant environmental disturbances.
- The medium (air) is stationary and homogeneous.

In real-world scenarios, deviations from these assumptions can lead to complex acoustic phenomena requiring advanced modeling.

Critical Analysis and Future Directions

Enhancing Measurement Accuracy

Future research involves developing more precise models that incorporate:

- Variable environmental conditions.
- Non-uniform train velocities.
- Transient effects during acceleration and deceleration phases.

Technological Innovations

Advancements in sensor technology could:

- Improve detection of Doppler-shifted signals.
- Enable real-time monitoring of moving sources.
- Enhance safety protocols in high-speed transportation.

Educational and Outreach Opportunities

Using scenarios like a receding train's whistle provides valuable educational tools:

- Demonstrating fundamental physics concepts.
- Engaging students with real-world applications.
- Developing interactive simulations for physics education.

Conclusion

The scenario of a train moving away from a station at 50 m/s, with a whistle emitting at 520 Hz, exemplifies the practical application of the Doppler effect. The calculated perceived frequency of approximately 453 Hz underscores how relative motion influences sound perception, with implications spanning safety, engineering, and scientific research. Recognizing these effects is essential not only for understanding fundamental physics but also for designing effective transportation systems and acoustic technologies. As speeds and technologies increase, ongoing research and innovation will continue to deepen our grasp of these phenomena, ensuring safer and more efficient communication in dynamic environments.

References

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from [relevant educational sources].

Note: All calculations assume standard atmospheric conditions and idealized physics models. Real-world observations may vary slightly due to environmental factors.

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