

A Truck Moving At 36 M/s Passes A Police Car Moving At 45 M/s In The Opposite Direction. If The Frequency

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Understanding the dynamics of objects moving at high speeds involves a nuanced grasp of relative velocity, wave phenomena, and the Doppler effect. In this article, we explore a scenario where a truck traveling at 36 meters per second (m/s) passes a police car moving at 45 m/s in the opposite direction. We analyze the situation from multiple perspectives, including relative motion, wave frequency alterations, and real-world applications such as radar detection. This comprehensive guide aims to clarify the physics involved and provide insights into how frequency changes occur in such high-speed encounters.

Understanding the Scenario: Basic Details

Before diving into complex calculations, it is essential to understand the fundamental parameters of the problem:

- Speed of the truck: 36 m/s
- Speed of the police car: 45 m/s
- Direction of movement: Opposite directions
- Objective: To analyze the frequency changes, possibly related to wave phenomena such as sound or radar signals

This setup is typical in collision detection, traffic monitoring, and radar systems where the relative motion impacts how signals are perceived or measured.

Fundamental Concepts: Relative Velocity and Doppler Effect

To interpret the problem accurately, grasping the concepts of relative velocity and the Doppler effect is crucial.

Relative Velocity

- Definition: The velocity of one object with respect to another.
- Calculation: When two objects move in opposite directions, their relative velocity is the sum of their speeds.

$$v_{\text{rel}} = v_{\text{truck}} + v_{\text{police}}$$

- Application in the scenario:

$$v_{\text{rel}} = 36 \text{ m/s} + 45 \text{ m/s} = 81 \text{ m/s}$$

This indicates that, from the perspective of either vehicle, the other approaches at 81 m/s.

The Doppler Effect

- Definition: The change in frequency or wavelength of a wave in relation to an observer moving relative to the source of the wave.
- Relevance: When either the source or the observer is moving, the frequency perceived differs from the emitted frequency.
- Key Factors:
 - Speed of the wave in the medium (sound or electromagnetic)
 - Relative velocity between source and observer
 - Frequency of the emitted wave

Analyzing the Frequency Change in the Scenario

The question often posed in such contexts involves determining how the frequency of a signal (sound or radar) is perceived by an observer when both are moving in opposite directions.

Assumptions for Calculation

- The wave in question is sound (e.g., siren or horn).
- The source is the police car, and the observer is the truck, or vice versa.
- The medium is air, and the wave speed (speed of sound) in air is approximately 343 m/s at room temperature.
- The emitted frequency (original frequency) is known, or we are to find the perceived frequency.

Formulating the Doppler Effect Equation

For a moving source and a moving observer, the general formula for the observed frequency f' is:

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

Where:

- f = emitted frequency
- v = speed of sound in the medium (approx. 343 m/s)
- v_o = velocity of the observer relative to the medium (positive if moving towards the source)
- v_s = velocity of the source relative to the medium (positive if moving away from the observer)

Since the vehicles are moving towards each other in opposite directions:

- The truck perceives an increased frequency.
- The police car (source) perceives a different frequency, depending on its motion relative to the wave source.

Calculating the Perceived Frequency

Suppose the police car emits a sound wave at a frequency f . Let's determine the frequency perceived by the truck.

Parameters for Calculation

- Source (Police Car): Moving at 45 m/s
- Observer (Truck): Moving at 36 m/s
- Both are moving towards each other, so:

$$v_o = v_{\text{truck}} = 36 \text{ m/s}$$

$$v_s = v_{\text{police}} = 45 \text{ m/s}$$

Note: Since both are moving towards each other, for the observer (truck):

- The observer is moving towards the source, so (v_o) is positive.
- The source is moving towards the observer, so (v_s) is positive.

Applying the Doppler Formula

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

$$f' = f \times \frac{343 + 36}{343 - 45} = f \times \frac{379}{298} \approx f \times 1.27$$

Interpretation:

- The truck perceives the sound at approximately 27% higher frequency than emitted.

Similarly, the police car would perceive the sound emitted by the truck at a different frequency, which can be calculated if needed.

Implications in Radar and Traffic Monitoring

The principles discussed extend beyond sound waves to electromagnetic waves used in radar systems for speed detection.

Radar Speed Detection

- Working Principle: Radar guns emit electromagnetic waves that reflect off moving vehicles.
- Frequency Shift: The Doppler effect causes a shift in the reflected wave's frequency proportional to the vehicle's speed.
- Formula for Radar Doppler Shift:

$$f' = f \times \frac{v + v_{\text{observer}}}{v - v_{\text{source}}}$$

Where:

- v is the speed of electromagnetic waves (speed of light, approximately $3 \times 10^8 \text{ m/s}$)
- Because $v \gg v_{\text{vehicle}}$, the Doppler shift is very small, but detectable with precise instruments.

Calculating the Doppler Shift for Radar

Given the vehicle's speed:

$$\Delta f \approx \frac{2 v_{\text{vehicle}}}{c} \times f$$

Where:

- c = speed of light ($\sim 3 \times 10^8 \text{ m/s}$)
- f = original radar frequency

For example, with a typical radar frequency of 10 GHz:

$$\Delta f \approx \frac{2 \times 36}{3 \times 10^8} \times 10^{10} = \frac{72}{3 \times 10^8} \times 10^{10}$$

$\approx 2.4 \text{ Hz}$

This shift is detectable and used to calculate vehicle speed accurately.

Real-World Applications and Significance

Understanding the physics behind high-speed object interactions has vital applications:

- Traffic Law Enforcement: Using radar guns to measure vehicle speeds accurately.
- Collision Avoidance Systems: Modern vehicles equipped with radar and lidar use Doppler principles for safety.
- Aerospace and Navigation: Doppler shift informs satellite communication and navigation systems.
- Acoustic Engineering: Designing sound systems and noise control to account for Doppler effects.

Summary and Key Takeaways

- When two objects move in opposite directions, their relative velocity is the sum of their speeds.
- The Doppler effect causes a perceived increase or decrease in wave frequency based on relative motion.
- For sound waves, the perceived frequency can be calculated using the Doppler formula, considering the speeds of source and observer.
- In electromagnetic systems like radar, the Doppler shift is typically very small but measurable and critical for speed detection.
- Real-world technologies leverage these principles for traffic enforcement, navigation, and safety systems.

Conclusion

The interaction of high-speed vehicles traveling in opposite directions presents a fascinating study of relative motion and wave phenomena. Whether analyzing the perceived sound frequency or the Doppler shift in radar signals, the core physics principles remain consistent. Grasping these concepts enhances our

understanding of modern traffic monitoring technologies, safety mechanisms, and communication systems. As vehicles and detection systems become more advanced, the importance of accurately understanding and applying relative velocity and Doppler effect principles continues to grow, ensuring safer roads and more efficient transportation networks.

Keywords: high-speed vehicles, Doppler effect, relative velocity, radar detection, traffic monitoring, sound waves, electromagnetic waves, vehicle speed, physics, wave frequency, collision avoidance

Frequently Asked Questions

What is the relative speed of the truck and police car when moving in opposite directions?

The relative speed is the sum of their speeds, so $36 \text{ m/s} + 45 \text{ m/s} = 81 \text{ m/s}$.

How does the relative speed affect the observed frequency of a sound emitted by one vehicle as heard by the other?

The observed frequency increases with relative speed due to the Doppler effect; higher relative speed results in a higher frequency heard.

If the police car emits a siren at a frequency of 1000 Hz, what frequency does the truck perceive as it passes by?

Using the Doppler effect for a source moving towards the observer, the perceived frequency is $f' = f (v + v_o) / (v - v_s)$. Assuming the observer (truck) is moving towards the source (police car), and $v = 340 \text{ m/s}$, the perceived frequency can be calculated accordingly.

What is the significance of the Doppler effect in this scenario?

The Doppler effect explains how the perceived frequency of the siren changes as the vehicles approach each other and after they pass, due to their relative motion.

How do you calculate the frequency heard by the truck when the police car emits a sound at a known frequency?

Use the Doppler formula: $f' = f (v + v_o) / (v - v_s)$, where v is the speed of sound, v_o is the observer's speed, v_s is the source's speed. Assign positive or negative values based on direction.

What assumptions are made in calculating the Doppler shift in this context?

Assumptions include a constant speed of sound in air (typically 340 m/s), straight-line motion, and that the source and observer are moving directly towards or away from each other.

If the truck passes the police car, how does the perceived frequency change before and after passing?

Before passing, the perceived frequency is higher (if approaching), and after passing, it decreases (if moving away), due to the Doppler effect caused by relative motion.

Can the Doppler effect cause the siren to sound higher-pitched as the truck approaches?

Yes, as the truck approaches the stationary police car, the frequency of the siren appears higher due to the Doppler effect.

Why is understanding the Doppler effect important for traffic safety and vehicle communication?

Understanding the Doppler effect helps in designing emergency sirens and vehicle sensors, ensuring clear communication and alert signals in moving traffic conditions.

What additional information is needed to precisely calculate the change in perceived frequency?

The actual emitted frequency of the siren is needed along with the speeds and directions of both vehicles to perform precise calculations.

Additional Resources

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In the realm of physics, understanding the phenomena associated with moving objects, especially when it involves relative motion and wave interactions, provides profound insights into the fundamental principles governing our universe. The scenario involving a truck traveling at 36 meters per second passing a police car moving at 45 meters per second in the opposite direction epitomizes such a situation where relative velocities and wave phenomena intersect. This article delves into the detailed physics behind the problem,

explores the concept of frequency shifts—most notably the Doppler effect—and provides a comprehensive analysis suitable for students, educators, and enthusiasts eager to deepen their understanding of motion and wave behavior.

Understanding the Scenario: Basic Concepts and Context

1. The Setting of the Problem

Imagine a highway where two vehicles are moving in opposite directions. A truck, a large freight vehicle, is moving at 36 meters per second. Simultaneously, a police car is moving at 45 meters per second in the opposite direction. The question posed revolves around the change in observed frequency of a wave—such as sound waves emitted by the vehicles—due to their relative motion.

2. Significance of Relative Velocity

The velocities indicated are in meters per second, a standard SI unit for speed. When objects move relative to each other, the observed frequencies of waves emitted or reflected by these objects are affected—a phenomenon known as the Doppler effect. Recognizing the relative velocity between the source and the observer is crucial because it determines the magnitude and direction of the frequency shift.

3. Wave Phenomena in Moving Vehicles

In real-world scenarios, the frequency in question often pertains to sound waves emitted by engines, sirens, or other sources associated with the vehicles. The Doppler effect explains how the perceived pitch of these sounds varies depending on the relative motion of source and observer.

Fundamental Principles: Motion and Wave Behavior

1. The Doppler Effect: An Overview

The Doppler effect describes the change in frequency or wavelength 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 types.

Key points include:

- When the source and observer approach each other, the observed frequency increases.
- When they move apart, the observed frequency decreases.
- The effect depends on the relative velocity along the line of sight.

2. Mathematical Formulation of the Doppler Effect

For sound waves in a medium like air, the observed frequency f' is related to the emitted frequency f by the formula:

$$f' = f \times \frac{v \pm v_o}{v \pm v_s}$$

Where:

- v = speed of sound in the medium (air), approximately 343 m/s at 20°C.
- v_o = velocity of the observer relative to the medium (positive if moving towards the source).
- v_s = velocity of the source relative to the medium (positive if moving away from the observer).

Note: The choice of signs depends on the relative motion direction.

Analyzing the Given Data: Step-by-Step Approach

1. Assigning Directions and Sign Conventions

To apply the Doppler formula, establish a coordinate system:

- Let's define the direction of the police car as the positive x-axis.
- Since the vehicles move in opposite directions, their velocities are in opposite signs relative to this axis.

Given:

- Truck velocity, $v_s = -36 \text{ m/s}$ (assuming positive direction is police car's movement).
- Police car velocity, $v_o = +45 \text{ m/s}$.

Note: The negative sign for the truck indicates it is moving in the opposite direction to the police car.

2. Understanding Source and Observer Roles

The key question involves the perceived frequency—possibly of the sound emitted by one of the vehicles or a wave reflected off the moving objects—due to their relative motion.

- If considering the police siren as the source and the truck as the observer, or vice versa, one applies the formula accordingly.
- If the problem involves reflection (like an echo), the analysis becomes more complex, involving double Doppler shifts.

In this case, let's assume the police siren is emitting a sound wave at frequency f , and the question pertains to the frequency observed by the truck or the police car.

Calculating the Observed Frequency: Applying the Doppler Effect

1. Scenario: Police Car as Source, Truck as Observer

Suppose the police car emits a sound wave at frequency f . The observed frequency by the truck is:

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

Where:

- $v = 343 \text{ m/s}$ (speed of sound in air).
- $v_o = 36 \text{ m/s}$ (truck approaching the source).
- $v_s = 45 \text{ m/s}$ (source moving towards the observer).

Note: Since the police car is moving towards the truck, the source and observer are approaching each other, so signs are considered accordingly.

Plugging in values:

$$f' = f \times \frac{343 + 36}{343 - 45} = f \times \frac{379}{298} \approx f \times 1.27$$

This indicates the truck perceives the sound at approximately 27% higher frequency than emitted.

2. Scenario: Truck as Source, Police Car as Observer

Alternatively, if the truck emits a sound and the police car observes it:

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

Here,

- $v_s = 36 \text{ m/s}$ (source moving towards the observer).

- $v_o = 45 \text{ m/s}$ (observer approaching the source).

Calculating:

$$f' = f \times \frac{343 + 45}{343 - 36} = f \times \frac{388}{307} \approx f \times 1.264$$

Again, a significant increase in perceived frequency occurs.

Broader Implications and Real-World Applications

1. Doppler Effect in Traffic and Emergency Services

The principles outlined are pivotal in understanding how sirens and horns are perceived at different distances and speeds. Emergency vehicles utilize the Doppler effect—altering siren pitch—to alert drivers effectively, especially at high speeds. Similarly, traffic enforcement agencies often rely on radar guns that exploit the Doppler effect to measure vehicle speeds accurately.

2. Wave Reflection and Doppler Shift

In more complex scenarios, like radar detection or sonar, the wave emitted reflects off moving objects. The observed frequency after reflection involves a double Doppler shift, effectively amplifying the frequency change depending on the relative velocities.

3. Applications in Astronomy and Communication

Beyond terrestrial traffic, Doppler considerations are fundamental in astronomy for measuring stellar and galactic velocities. In communication technology, understanding wave frequency shifts ensures signal integrity across moving platforms like satellites and spacecraft.

Critical Factors and Assumptions in Analysis

1. Speed of Sound Variability

The speed of sound in air varies with temperature, humidity, and pressure. The standard value (343 m/s at 20°C) is used for typical calculations but can differ in real conditions.

2. Medium Uniformity and Environmental Factors

Environmental noise, wind, and atmospheric conditions influence wave propagation and perceived frequency shifts.

3. Signal Nature and Source Characteristics

The analysis assumes continuous, monochromatic waves emitted at a fixed frequency. Real-world signals might be complex, requiring Fourier analysis for detailed understanding.

Conclusion: Integrating Motion and Wave Theory

The scenario of a truck moving at 36 m/s passing a police car traveling at 45 m/s in the opposite direction vividly illustrates the profound effects of relative motion on wave phenomena. The Doppler effect explains how the perceived frequency can increase significantly due to the approaching motion of both source and observer. Calculations reveal that a source emitting a certain frequency would be perceived at approximately 27-27.5% higher frequency by the approaching vehicle.

This analysis underscores the importance of understanding relative velocities, wave behavior, and their applications across various fields—ranging from traffic management to astrophysics. Recognizing the fundamental physics governing these phenomena not only enriches our comprehension of everyday

experiences but also enhances technological advancements that rely on wave-based detection and communication systems.

Whether in the bustling traffic of a highway or the vast expanse of space, the principles outlined demonstrate the universal applicability of wave motion and relative velocity concepts, reaffirming their central role in scientific inquiry and technological innovation.

References:

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