

A Student Gives A 25 N Push Against A 10 Kg Stationary Cart For 3 Seconds. Determine The Final Velocity

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When analyzing real-world physics problems, especially those involving forces, mass, and motion, it becomes essential to understand the fundamental principles of Newtonian mechanics. In this scenario, a student applies a force to a stationary cart over a specific period, and our goal is to determine the cart's final velocity after this interaction. Such problems not only reinforce core concepts like Newton's Second Law but also demonstrate how to apply these principles practically.

Understanding the Scenario

Before diving into calculations, let's clarify the problem's details:

Given Data:

- Force applied by the student, $F = 25 \text{ N}$
- Mass of the cart, $m = 10 \text{ kg}$
- Duration of force application, $t = 3 \text{ seconds}$
- Initial velocity of the cart, $u = 0 \text{ m/s}$ (stationary)

The question asks: What is the final velocity of the cart after the student pushes it for 3 seconds?

Fundamental Concepts in Physics Involved

To solve this problem, we need to understand and apply several key physics principles:

Newton's Second Law of Motion

- States that force acting on an object equals the mass of the object multiplied by its acceleration:

$$F = m a$$

- Rearranged to find acceleration:

$$a = F / m$$

Kinematic Equations

- Describe the motion of objects under constant acceleration:

- Final velocity: $v = u + a t$
- Displacement: $s = u t + 0.5 a t^2$

In this problem, since the force is applied over a known time, and the initial velocity is zero, these equations are directly applicable.

Calculating the Acceleration

The first step is to determine the acceleration imparted to the cart by the applied force.

Applying Newton's Second Law

- Given:

$$F = 25 \text{ N}$$

$$m = 10 \text{ kg}$$

- Calculating acceleration:

$$a = F / m = 25 \text{ N} / 10 \text{ kg} = 2.5 \text{ m/s}^2$$

This acceleration indicates that, during the push, the cart's velocity increases at 2.5 meters per second squared.

Calculating the Final Velocity

Now, using the kinematic equation suitable for constant acceleration:

Final velocity calculation:

- Initial velocity, $u = 0 \text{ m/s}$
- Acceleration, $a = 2.5 \text{ m/s}^2$
- Time, $t = 3 \text{ seconds}$

Applying the equation:

$$v = u + a t = 0 + 2.5 \cdot 3 = 7.5 \text{ m/s}$$

Therefore, the final velocity of the cart after 3 seconds of pushing is 7.5 meters per second.

Deeper Insights and Additional Considerations

While the calculation appears straightforward, exploring related concepts and potential real-world complications can deepen understanding.

1. Impulse and Momentum

- Impulse is the change in momentum resulting from a force applied over a period:

$$\text{Impulse } (J) = F t$$

- For this case:

$$J = 25 \text{ N} \cdot 3 \text{ s} = 75 \text{ N}\cdot\text{s}$$

- The change in momentum (Δp) equals impulse:

$$\Delta p = m v_{\text{final}} - m u = J$$

- Since initial velocity $u = 0$:

$$m v_{\text{final}} = J$$

$$v_{\text{final}} = J / m = 75 \text{ N}\cdot\text{s} / 10 \text{ kg} = 7.5 \text{ m/s}$$

This confirms our previous calculation via kinematic equations.

2. Assumptions in the Calculation

- The force applied is constant over the entire 3 seconds.
- There are no other forces acting on the cart, such as friction or air resistance.
- The push starts from rest, with initial velocity zero.
- The push is direct and purely in one direction.

In real-life scenarios, factors like friction could reduce the velocity, or the force might not be perfectly constant, affecting the outcome.

3. Effect of Friction and External Forces

- If friction were present, it would oppose the motion, effectively reducing the net force.
- To incorporate friction:
 - Determine the frictional force, usually μN , where μ is the coefficient of friction, and N is the normal force (equal to $m g$).
 - Calculate net force: $F_{\text{net}} = \text{applied force} - \text{frictional force}$.
- The net acceleration would then be:

$$a_{\text{net}} = F_{\text{net}} / m$$

- The final velocity would be less than 7.5 m/s depending on the magnitude of friction.

Real-World Applications and Broader Context

Understanding how forces influence motion is crucial in numerous real-world applications:

1. Engineering and Design

- Designing carts, vehicles, or machinery requires knowing how forces translate into motion.
- Engineers use these calculations to optimize force application for desired speeds.

2. Sports Science

- Athletes' pushes, throws, or sprints involve similar physics principles.
- Coaches analyze force and acceleration to improve performance.

3. Safety and Accident Analysis

- Accident reconstruction often involves calculating velocities based on applied forces over time.

4. Educational Purposes

- Demonstrating these concepts helps students grasp the fundamentals of physics.

Summary and Final Thoughts

To recap:

- The force applied by the student is 25 N.
- The cart's mass is 10 kg.
- The force is applied over 3 seconds.
- Assuming no other forces act on the cart, the acceleration is 2.5 m/s^2 .
- Using kinematic equations, the final velocity after 3 seconds is 7.5 m/s .
- Impulse calculations confirm this result, illustrating the relationship between force, time, and momentum.

This problem provides a clear illustration of Newtonian mechanics in action, demonstrating how a constant force affects an object's motion over time. Understanding these principles is essential for students, engineers, and scientists working in fields where motion and forces intersect.

Additional Practice Problems

To further reinforce your understanding, consider exploring similar problems:

1. What would be the final velocity if the same force is applied for 5 seconds?
2. If friction opposes the motion with a force of 2 N, what is the new final velocity?
3. How much work is done by the student during the push?

References and Further Reading

- "Physics Principles with Applications" by Douglas C. Giancoli
- Online resources such as Khan Academy's Physics section
- Educational websites for interactive physics simulations

In conclusion, by analyzing the forces, applying Newton's Second Law, and using kinematic equations, we determine that the cart's final velocity after a 3-second push of 25 N is 7.5 m/s. This problem exemplifies the core ideas of classical mechanics and their practical applications across various fields.

Frequently Asked Questions

What is the main principle used to determine the final velocity of the cart after the push?

The main principle is the conservation of momentum, applying the impulse-momentum theorem which relates the force and time to the change in momentum.

How do you calculate the impulse applied to the cart?

Impulse is calculated by multiplying the force exerted by the time during which it acts: $\text{Impulse} = \text{Force} \times \text{Time}$. In this case, $25 \text{ N} \times 3 \text{ s} = 75 \text{ N}\cdot\text{s}$.

What is the initial momentum of the stationary cart?

Since the cart is initially stationary, its initial momentum is zero.

How do you find the final velocity of the cart using impulse and momentum?

Use the impulse-momentum theorem: $\text{Final momentum} = \text{Initial momentum} + \text{Impulse}$. Since initial momentum is zero, $\text{Final momentum} = 75 \text{ N}\cdot\text{s}$. Then, divide by the cart's mass to find velocity: $v = \Delta p / m$.

What is the final velocity of the cart after the push?

$\text{Final velocity} = \text{Impulse} / \text{mass} = 75 \text{ N}\cdot\text{s} / 10 \text{ kg} = 7.5 \text{ m/s}$.

Does the duration of the push affect the final velocity? If so, how?

Yes, the longer the force is applied (assuming constant force), the larger the impulse and thus the greater the final velocity of the cart.

What assumptions are made in this calculation?

Assumptions include that the force remains constant during the push, external forces like friction are negligible, and the system is isolated during the interaction.

If the student applied a smaller force for a longer duration, how would that impact the final velocity?

It could produce the same or different final velocity depending on the product of force and time (impulse). If the total impulse remains the same, the final velocity would be unchanged; otherwise, it would differ.

What real-world factors could cause the actual final velocity to differ from the calculated value?

Factors such as friction, air resistance, inaccuracy in force measurement, or non-constant force application could cause deviations from the ideal calculated velocity.

Additional Resources

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Introduction

In the realm of classical mechanics, understanding how forces influence motion is fundamental. A common scenario involves a person applying a force to an object, resulting in acceleration or deceleration based on the interaction. This article delves into a specific case: a student applies a 25 N force to a stationary cart for a duration of 3 seconds. Our goal is to determine the cart's final velocity after this force application, employing Newtonian physics principles. This case study exemplifies core concepts such as Newton's second law, impulse, and momentum, providing clarity for students, educators, and enthusiasts alike.

Context and Scenario Overview

Imagine a student standing beside a flat surface where a small, stationary cart is placed. The student exerts a consistent push of 25 N for exactly 3 seconds. Initially, the cart is at rest, and the environment is assumed to be free of friction or external influences such as air resistance. Under these ideal conditions, the question arises: What is the cart's velocity immediately after the push?

This scenario encapsulates several key physics concepts:

- The relationship between force and acceleration
- The role of time in determining change in momentum
- The calculation of final velocity from known forces and durations

To analyze this, we will systematically apply Newtonian mechanics, starting with fundamental equations.

Fundamental Principles and Theoretical Framework

Newton's Second Law of Motion

Newton's second law states:

$$F = m a$$

where:

- F is the net force applied to an object
- m is the mass of the object
- a is the acceleration produced

Rearranged to solve for acceleration:

$$a = \frac{F}{m}$$

In this scenario:

- $F = 25 \text{ N}$
- $m = 10 \text{ kg}$

Thus:

$$a = \frac{25 \text{ N}}{10 \text{ kg}} = 2.5 \text{ m/s}^2$$

This acceleration occurs during the push duration, which is 3 seconds.

Impulse-Momentum Theorem

Impulse (J) is defined as:

$$J = F \times \Delta t$$

where:

- Δt is the duration of the force application

Impulse relates to the change in momentum:

$$J = \Delta p = m v_f - m v_i$$

Given that the initial velocity (v_i) is zero (stationary cart), the final velocity (v_f) can be found by:

$$v_f = \frac{J}{m}$$

Step-by-Step Calculation

1. Calculating Impulse

Given:

- Force ($F = 25\text{ N}$)
- Time ($\Delta t = 3\text{ seconds}$)

Impulse:

$$J = F \times \Delta t = 25\text{ N} \times 3\text{ s} = 75\text{ N}\cdot\text{s}$$

2. Determining Final Velocity

Since the initial velocity is zero:

$$v_i = 0$$

The change in momentum:

$$\Delta p = J = 75\text{ N}\cdot\text{s}$$

Thus:

$$v_f = \frac{\Delta p}{m} = \frac{75\text{ N}\cdot\text{s}}{10\text{ kg}} = 7.5\text{ m/s}$$

Final velocity of the cart after the push is 7.5 m/s in the direction of the applied force.

Assumptions and Ideal Conditions

The above calculation assumes:

- No friction or resistive forces acting on the cart during the push.
- The force remains constant at 25 N throughout the entire 3 seconds.
- The push occurs strictly along a straight line without any angular components.
- The initial velocity of the cart is zero, and the push is applied uniformly.

In real-world scenarios, friction, air resistance, and variations in applied force can affect the outcome. However, for theoretical analysis and ideal conditions, these calculations hold.

Deeper Analysis: Considering Real-World Factors

Frictional Forces

In practical situations, friction between the cart wheels and the surface opposes motion. The static friction initially resists movement, but once the cart overcomes static friction and begins to move, kinetic friction acts against it. The force of kinetic friction is:

$$f_k = \mu_k N$$

where:

- μ_k is the coefficient of kinetic friction
- N is the normal force, equal to (mg) for horizontal surfaces

If friction is significant, the net force becomes:

$$F_{\text{net}} = F - f_k$$

and the acceleration is:

$$a_{\text{net}} = \frac{F_{\text{net}}}{m}$$

which would reduce the final velocity.

Variable Force Application

In real situations, maintaining a perfectly constant force over 3 seconds is challenging. Variations in force would lead to a different impulse and thus a different final velocity.

Advanced Considerations: Rotational Effects and Energy

Although not directly applicable here, considering rotational effects or energy transfer can deepen understanding. For example:

- The work done by the force:

$$W = F \times d$$

where d is the displacement during the push, can be used to compute the kinetic energy:

$$KE = \frac{1}{2} m v_f^2$$

Given the impulse approach, the work-energy theorem confirms the same final velocity.

Practical Implications and Educational Significance

This scenario serves as a practical demonstration of fundamental physics principles:

- Impulse-momentum relationship: How a force applied over a time interval changes an object's momentum.
- Role of mass: How increasing mass decreases acceleration for the same force.
- Time dependence: Longer force application results in higher velocity, assuming constant force.

For educators, this example emphasizes the importance of understanding the interplay between force, time, and momentum, and provides a clear illustration suitable for physics labs, demonstrations, and problem-solving exercises.

Limitations and Further Research

While the calculations provide a clear theoretical answer, real-world applications would require considering:

- Frictional forces
- Force variations
- External influences like air resistance
- Surface conditions and material properties

Further research could involve experimental validation, measuring actual forces and velocities, or exploring how different surface conditions influence the outcome.

Conclusion

In an idealized physics problem, a student applying a constant 25 N force to a 10 kg stationary cart for 3 seconds imparts an impulse of 75 N·s, resulting in a final velocity of 7.5 m/s. This straightforward calculation exemplifies core principles of Newtonian mechanics, emphasizing the fundamental relationship between force, time, and momentum. Such problems deepen conceptual understanding and serve as foundational exercises for students exploring the dynamics of motion, illustrating the power of classical physics in predicting real-world phenomena.

References

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Note: This article provides a comprehensive review of the physics involved in a force application scenario, suitable for academic audiences or educational content creators seeking detailed analysis and explanations.

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