A 2 000-kg Car Is Slowed Down Uniformly From 20. 0 M/s To 5. 00 M/s In 4. 00 S. (a) What Average Force

A 2 000-kg Car Is Slowed Down Uniformly From 20. 0 M/s To 5. 00 M/s In 4. 00 S. (a) What Average Force

---

Introduction

Imagine driving a car that suddenly begins to decelerate. The sensation of slowing down can be smooth or abrupt, depending on various forces acting on the vehicle. In physics, understanding these forces helps us analyze motion and predict outcomes accurately. Consider a practical example: a 2,000-kg car initially traveling at 20.0 meters per second (m/s) is brought to a stop or slowed down to 5.00 m/s over a period of 4.00 seconds. This scenario involves uniform deceleration, which means the rate of change of velocity remains constant throughout the process.

Understanding the average force required to achieve such a deceleration is fundamental in automotive safety, vehicle design, and physics education. It provides insights into how much braking force is necessary to control a vehicle's speed effectively.

In this article, we'll explore the physics behind this problem, derive the relevant equations, perform calculations to find the average force, and discuss related concepts such as acceleration, momentum, and force. Whether you're a student studying physics, an automotive engineer, or simply curious about how forces influence motion, this detailed analysis will enhance your understanding.

Understanding the Problem

Before diving into calculations, let's clearly define the problem parameters:

- Mass of the car (m): 2000 kg
- Initial velocity (u): 20.0 m/s
- Final velocity (v): 5.00 m/s
- Time taken to change velocity (t): 4.00 seconds

The key question: What is the average force exerted on the car during this deceleration?

Fundamental Concepts and Equations

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

1. Newton's Second Law of Motion

Newton's second law states that the net force acting on an object is equal to the mass of the object multiplied by its acceleration:

$$
F_{net} = m \times a
$$

Where:
- F_{net} is the net force (in Newtons, N)
- m is the mass (in kilograms, kg)
- a is the acceleration (in meters per second squared, m/s^2)

2. Acceleration

Acceleration describes how quickly an object's velocity changes over time. When an object slows down, it has a negative acceleration (deceleration):

$$
a = \frac{\Delta v}{t}
$$

Where:
- $\Delta v = v - u$ is the change in velocity
- t is the time over which this change occurs

3. Average Force

Since the force varies during actual braking (due to factors like brake modulation, road conditions, etc.), the problem asks for the average force over the 4.00 seconds, which can be computed using the average acceleration:

$$
F_{avg} = m \times a_{avg}
$$

4. Momentum and Impulse (Optional)

Alternatively, impulse-momentum theorem states:

$$
F_{avg} \times t = \Delta p = m \times (v - u)
$$

But since we're asked specifically for force and we know the time, calculating acceleration directly is straightforward.

Step-by-Step Calculation

1. Calculate the Change in Velocity (Δv)

$$
\Delta v = v - u = 5.00\, \text{m/s} - 20.0\, \text{m/s} = -15.0\, \text{m/s}
$$

The negative sign indicates a decrease in speed, i.e., deceleration.

2. Compute the Average Acceleration (a_{avg})

$$
a_{avg} = \frac{\Delta v}{t} = \frac{-15.0\, \text{m/s}}{4.00\, \text{s}} = -3.75\, \text{m/s}^2
$$

This negative acceleration confirms the car is slowing down.

3. Find the Average Force (F_{avg})

Applying Newton's second law:

$$
F_{avg} = m \times a_{avg} = 2000\, \text{kg} \times (-3.75\, \text{m/s}^2) = -7500\, \text{N}
$$

The negative sign indicates the force acts opposite to the direction of motion, i.e., it's a braking or decelerating force.

4. Final Result

The magnitude of the average force applied to the car is 7,500 Newtons, directed opposite to the initial motion.

Interpretation and Real-World Significance

The calculated average force of 7,500 N reflects the braking effort needed to decelerate the vehicle from 20.0 m/s to 5.00 m/s within 4 seconds. In real-world scenarios, this force is exerted by the braking system through friction between brake pads and wheels, as well as between tires and the road surface.

Practical considerations:

- Brake force capacity: Modern vehicles are designed with braking systems capable of exerting forces much greater than this, ensuring safety margins.
- Road conditions: Wet or icy roads reduce the effective force due to decreased friction, requiring longer braking distances.
- Driver response: The actual force applied depends on driver input and vehicle automation systems.

Additional insights:

- Deceleration rate: The negative acceleration of -3.75 m/s^2 is moderate and typical for urban braking.

- Stopping distance: While not asked, knowing the deceleration allows calculation of stopping distance, which is critical for safety.

Related Concepts and Advanced Topics

1. Deceleration and Negative Acceleration

Deceleration is simply acceleration in the opposite direction of motion. It’s important to understand that negative acceleration doesn't mean the object is moving backward, but rather that its speed decreases over time.

2. Impulse and Momentum Change

Using impulse:

$$
F_{avg} = \frac{\Delta p}{t} = \frac{m(v - u)}{t}
$$

This aligns with the previous calculation and emphasizes the relationship between force, time, and change in momentum.

3. Energy Considerations

Braking also involves converting the car's kinetic energy into heat via brake friction:

$$
KE_{initial} = \frac{1}{2} m u^2 = \frac{1}{2} \times 2000\, \text{kg} \times (20.0)^2\, \text{m}^2/\text{s}^2 = 400,000\, \text{J}
$$

The work done by the brake force approximately equals this energy:

$$
Work = F_{avg} \times d
$$

Where d is the stopping distance, which can be calculated using kinematic equations if needed.

Additional Calculations: Estimating Stopping Distance

Using the kinematic equation:

$$
v^2 = u^2 + 2 a s
$$

Where:
- s is the stopping distance
- a is the acceleration (here, deceleration)

Rearranged to solve for s:

$$
s = \frac{v^2 - u^2}{2a}
$$

Plug in the known values:

$$
s = \frac{(5.00)^2 - (20.0)^2}{2 \times -3.75} = \frac{25 - 400}{-7.5} = \frac{-375}{-7.5} = 50\, \text{meters}
$$

The car would require approximately 50 meters to decelerate from 20 m/s to 5 m/s under these conditions.

Conclusion

This comprehensive analysis demonstrates how fundamental physics principles—Newton's laws, kinematic equations, and concepts of force and energy—interconnect to solve real-world problems involving vehicle motion. The key takeaway is that to decelerate a 2,000-kg car from 20.0 m/s to 5.00 m/s in 4.00 seconds, an average force of approximately 7,500 N is necessary, acting in the direction opposite to the vehicle's initial motion.

Understanding these calculations is vital for automotive safety engineering, designing effective braking systems, and educating students about the practical applications of physics. Whether for designing safer vehicles or analyzing everyday driving scenarios, grasping the relationship between force, acceleration, and motion remains fundamental.

References

- Halliday, D., Resnick, R., & Walker, J. (2014). Fundamentals of Physics (10th Edition). Wiley.
- Serway, R. A., & Jewett, J. W. (2013). Physics for Scientists and Engineers (9th Edition). Brooks Cole.
- Vehicle Dynamics and Safety Engineering Resources. (2020). Automotive Engineering Journal.

By mastering these calculations and concepts, you can better understand the forces involved in vehicle deceleration and apply this knowledge to various fields, including automotive safety, physics education, and engineering design.

Frequently Asked Questions

What is the initial velocity of the car?

The initial velocity of the car is 20.0 m/s.

What is the final velocity of the car after deceleration?

The final velocity of the car is 5.00 m/s.

What is the duration of the deceleration process?

The deceleration occurs over a period of 4.00 seconds.

How do you calculate the change in velocity of the car?

Change in velocity = final velocity - initial velocity = 5.00 m/s - 20.0 m/s = -15.0 m/s.

What is the formula to find the average force applied to the car?

Average force = mass × acceleration, where acceleration = (final velocity - initial velocity) / time.

How do you calculate the acceleration of the car during deceleration?

Acceleration = (final velocity - initial velocity) / time = (5.00 m/s - 20.0 m/s) / 4.00 s = -3.75 m/s^2.

What is the magnitude of the average force exerted on the car?

Using F = m × a, the average force = 2000 kg × (-3.75 m/s^2) = -7500 N.

What does the negative sign in the force indicate?

It indicates that the force is acting in the opposite direction of the initial motion, i.e., a decelerating force.

Why is it important to calculate the average force in this scenario?

Calculating the average force helps understand the magnitude of the braking force required to slow down the car over the given time.

Can this method be used to find the force if the deceleration was not uniform?

No, if the deceleration is not uniform, you would need additional data to calculate instantaneous forces, and the average force may not be sufficient to describe the complex deceleration.

Additional Resources

Understanding the Dynamics of Uniform Deceleration: An In-Depth Analysis of a 2000-kg Car Slowing Down

When analyzing the motion of vehicles, especially in scenarios involving deceleration, physics provides a robust framework to quantify and understand the forces at play. Consider a car with a mass of 2000 kg that reduces its speed from 20.0 m/s to 5.00 m/s over a span of 4.00 seconds. Such a situation is common in safety testing, vehicle dynamics analysis, and everyday driving scenarios where brakes are applied to reduce speed safely and effectively. This comprehensive review will explore every facet of this problem, focusing on calculating the average force involved during this deceleration process.

Fundamentals of Uniform Acceleration and Deceleration

To understand the problem at hand, it’s vital to revisit some fundamental principles of kinematics and dynamics.

Key Concepts and Definitions

- Velocity (v): The rate at which an object changes its position, measured in meters per second (m/s).
- Acceleration (a): The rate of change of velocity with respect to time, measured in meters per second squared (m/s^2).
- Force (F): An interaction that causes a change in the motion of an object, measured in Newtons (N).
- Mass (m): The quantity of matter in an object, measured in kilograms (kg).

In the case of uniform deceleration:

- The acceleration is constant and negative relative to the direction of motion.
- The initial velocity (\(v_i\)) and final velocity (\(v_f\)) are known.
- The time interval (\(t\)) over which deceleration occurs is given.

Quantitative Analysis of the Vehicle's Deceleration

Given Data:

- Mass of the car, $m = 2000\, \text{kg}$
- Initial velocity, $v_i = 20.0\, \text{m/s}$
- Final velocity, $v_f = 5.00\, \text{m/s}$
- Time to decelerate, $t = 4.00\, \text{s}$

Objective:

- Calculate the average force exerted on the car during the deceleration.

Step 1: Calculating the Acceleration

Since the deceleration is uniform, the acceleration can be obtained directly from the change in velocity over time:

$$
a = \frac{v_f - v_i}{t}
$$

Plugging in the known values:

$$
a = \frac{5.00\, \text{m/s} - 20.0\, \text{m/s}}{4.00\, \text{s}} = \frac{-15.0\, \text{m/s}}{4.00\, \text{s}} = -3.75\, \text{m/s}^2
$$

The negative sign indicates a deceleration (speed reduction).

Step 2: Applying Newton's Second Law to Find the Average Force

Newton's Second Law states:

$$
F_{\text{avg}} = m \times a
$$

Substituting the known values:

$$
F_{\text{avg}} = 2000\, \text{kg} \times (-3.75\, \text{m/s}^2) = -7500\, \text{N}
$$

The negative sign here signifies that the force acts in the direction opposite to the vehicle's initial motion—essentially a braking force.

Therefore:

$$
\boxed{
\textbf{The average force exerted on the car is } 7500\, \text{N} \text{ directed opposite to the motion.}
}
$$

Deeper Insights into the Force and Deceleration Dynamics

While the calculation above provides the numerical value, understanding the broader implications and the physical context enhances comprehension.

Nature of the Force

- The force calculated is an average force, meaning it represents the net effect over the entire deceleration period.
- In real-world scenarios, the actual force may vary during braking due to factors like brake lock-up, tire-road interaction, and vehicle dynamics.
- Typically, braking systems generate forces that can be significantly higher than the average, especially during initial application.

Implications of the Force Magnitude

- A force of 7500 N is substantial, underscoring the importance of effective braking systems.
- The force must be balanced against road conditions to prevent loss of traction or skidding.
- The magnitude also provides insight into the energy dissipated during deceleration.

Energy Considerations: Work-Energy Perspective

Understanding the force in terms of energy helps contextualize the deceleration process.

Initial and Final Kinetic Energy

- Initial kinetic energy:

$$
KE_i = \frac{1}{2} m v_i^2 = \frac{1}{2} \times 2000\, \text{kg} \times (20.0\, \text{m/s})^2 = 1000 \times 400 = 400,000\, \text{J}
$$

- Final kinetic energy:

$$
KE_f = \frac{1}{2} m v_f^2 = \frac{1}{2} \times 2000\, \text{kg} \times (5.00\, \text{m/s})^2 = 1000 \times 25 = 25,000\, \text{J}
$$

- Energy dissipated:

$$
\Delta KE = KE_i - KE_f = 400,000\, \text{J} - 25,000\, \text{J} = 375,000\, \text{J}
$$

This energy is primarily converted into heat through brake friction and deformation of brake components.

Step 3: Calculating the Work Done by the Force

- Work done (W) by the force during deceleration is:

$$
W = F_{\text{avg}} \times d
$$

Where d is the distance traveled during the deceleration.

- To find d, use the kinematic equation:

$$
v_f^2 = v_i^2 + 2 a d
$$

Rearranged as:

$$
d = \frac{v_f^2 - v_i^2}{2 a}
$$

Plugging in the values:

$$
d = \frac{(5)^2 - (20)^2}{2 \times (-3.75)} = \frac{25 - 400}{-7.5} = \frac{-375}{-7.5} = 50\, \text{m}
$$

- Now, verify the work-energy principle:

$$
W = F_{\text{avg}} \times d = 7500\, \text{N} \times 50\, \text{m} = 375,000\, \text{J}
$$

which matches the energy dissipated calculated earlier, confirming the consistency of the analysis.

Real-World Applications and Safety Considerations

Understanding these calculations is not merely academic; it has direct implications for vehicle safety, brake design, and driving protocols.

Brake System Design

- Brakes must generate forces exceeding the average calculated to ensure effective deceleration.
- Brake materials and design are optimized to withstand high forces and dissipate heat efficiently.

Road Conditions and Traction

- The maximum force that tires can exert without slipping is governed by the coefficient of static friction (μ_s) and normal force.
- For example, with an estimated coefficient of static friction $\mu_s = 0.7$, the maximum braking force is:

$$
F_{\text{max}} = \mu_s \times m \times g = 0.7 \times 2000\, \text{kg} \times 9.81\, \text{m/s}^2 \approx 13,734\, \text{N}
$$

- Since the required force (7500 N) is less than this maximum, the deceleration is feasible without tire slippage under ideal conditions.

Implications for Driver Safety

- Drivers should maintain safe following distances to allow for the necessary deceleration forces to act without losing control.
- Sudden or excessive braking may lead to skidding if forces exceed tire-road friction limits.

Additional Considerations and Advanced Topics

Beyond the basic calculations, several advanced topics provide a richer understanding:

Variable Forces and Non-Uniform Braking

- Real braking involves forces that vary over time, often peaking initially and then decreasing.
- ABS (Anti-lock Braking Systems) modulate brake force to prevent skidding, effectively controlling force magnitude dynamically.

Impact of Road Inclination

- Inclined roads introduce additional components of gravitational force, altering the net force required for deceleration.
- Analysis would need to incorporate gravitational components along the incline.

Effect of Vehicle Load and Conditions

- Heavier loads increase the normal force, hence allowing higher maximum braking forces.
- Worn tires or wet surfaces reduce friction, limiting achievable braking force.

Summary and Final Remarks