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to a fixed support. This scenario is a classic problem in classical mechanics that involves principles of conservation of momentum, energy transfer, and collision dynamics.

Understanding what happens during such an inelastic collision — where the bullet becomes embedded within the block — provides valuable insights into real-world applications such as ballistic testing, impact analysis, and safety engineering. In this comprehensive article, we will delve into the physics principles involved, step-by-step calculations, and practical implications of this problem, all organized for clarity and SEO optimization.

Overview of the Problem

In this scenario, a bullet with a known mass and initial velocity strikes a stationary block, becomes embedded within it, and causes the combined system to move with a certain velocity. The key points are:

- Bullet mass: 16.2 grams
- Initial bullet speed: 850 meters per second (m/s)
- Block mass: 40.0 kilograms (kg)
- Block initial velocity: 0 m/s (stationary)
- Post-collision behavior: The bullet embeds in the block, and the combined system moves together after impact.

The central question is: What is the velocity of the combined block and embedded bullet immediately after the collision?

Fundamental Concepts Involved

1. Conservation of Momentum

In an isolated system with no external forces during the collision, momentum before the collision equals momentum after:

$$m_b v_b + m_{\text{block}} v_{\text{block}} = (m_b + m_{\text{block}}) v_{\text{final}}$$

where:

- m_b = mass of the bullet
- v_b = initial velocity of the bullet

- m_{block} = mass of the block
- v_{block} = initial velocity of the block (zero in this case)
- v_{final} = velocity of the combined system after embedding

2. Inelastic Collisions

Since the bullet embeds into the block, this is an inelastic collision. Kinetic energy is not conserved because some energy is dissipated as heat, sound, or deformation, but momentum is conserved.

3. Units and Conversions

- Mass units: grams to kilograms
- Velocity units: meters per second (m/s)

Step-by-Step Calculation

1. Convert Mass Units

$$m_b = 16.2 \text{ g} = 0.0162 \text{ kg}$$

$$m_{\text{block}} = 40.0 \text{ kg}$$

2. Apply Conservation of Momentum

Initial total momentum:

$$p_{\text{initial}} = m_b v_b + m_{\text{block}} v_{\text{block}} = 0.0162 \times 850 + 40.0 \times 0$$

$$p_{\text{initial}} = 13.77 \text{ kg}\cdot\text{m/s}$$

Final momentum:

$$p_{\text{final}} = (m_b + m_{\text{block}}) v_{\text{final}}$$

Since momentum is conserved:

$$p_{\text{initial}} = p_{\text{final}}$$

Solve for v_{final} :

$$v_{\text{final}} = \frac{p_{\text{initial}}}{m_b + m_{\text{block}}} = \frac{13.77}{0.0162 + 40.0}$$

$$v_{\text{final}} = \frac{13.77}{40.0162} \approx 0.344 \text{ m/s}$$

3. Interpretation of Results

The embedded system (bullet + block) moves at approximately 0.344 m/s immediately after impact.

Additional Considerations

1. Energy Loss and Kinetic Energy

While momentum is conserved, kinetic energy is not:

- Initial kinetic energy of the bullet:

$$KE_{\text{initial}} = \frac{1}{2} m_b v_b^2 = \frac{1}{2} \times 0.0162 \times 850^2 \approx 5874 \text{ J}$$

- Kinetic energy of the combined system after impact:

$$KE_{\text{final}} = \frac{1}{2} (m_b + m_{\text{block}}) v_{\text{final}}^2 \approx \frac{1}{2} \times 40.0162 \times 0.344^2 \approx 2.37 \text{ J}$$

- Energy dissipated (lost):

$$\Delta KE = KE_{\text{initial}} - KE_{\text{final}} \approx 5874 - 2.37 \approx 5871.63 \text{ J}$$

This significant energy loss illustrates the inelastic nature of the collision.

2. Practical Implications

- Ballistics Testing: Understanding how a projectile embeds and transfers energy can inform the design of protective gear.
- Safety Engineering: Analyzing energy dissipation helps in constructing barriers that absorb impact.
- Material Science: Studying embedment and deformation informs material selection for impact resistance.

Advanced Topics

1. Impact of Friction and External Forces

In real-world scenarios, external forces such as friction, air resistance, or support constraints may influence the outcome. These factors are often negligible during short collision times but are critical in comprehensive analyses.

2. Post-Impact Motion and Oscillations

After embedding, the combined mass might oscillate if attached to a spring or suspension system. Analyzing such motion involves concepts of oscillatory dynamics and energy transfer.

3. Use of Conservation of Momentum in Different Frames

Understanding how the problem looks from different reference frames (e.g., moving or stationary observer) can provide further insights into impact physics.

Practical Examples and Applications

1. Ballistic Penetration Testing

Engineers use such calculations to simulate how projectiles embed in targets, influencing the design of protective armor and barriers.

2. Forensic Ballistics

Forensic experts analyze projectile embedding to determine impact speeds and projectile origins.

3. Material Impact Testing

Studying embedding phenomena helps in testing material resilience and deformation under high-velocity impacts.

Conclusion

The problem of a 16.2-g bullet embedding itself in a 40.0-kg block traveling at high speed encapsulates fundamental principles of physics, notably conservation of momentum and the characteristics of inelastic collisions. Through step-by-step calculations, we determined that the combined system moves at approximately 0.344 m/s immediately after impact, with a significant portion of the initial kinetic energy dissipated during the process. Such analyses are not only academically interesting but also practically vital across various fields including ballistics, safety engineering, and material science. Understanding the dynamics of inelastic collisions enables engineers and scientists to design safer, more resilient systems capable of managing high-energy impacts effectively.

Frequently Asked Questions (FAQs)

Q1: Why does the combined system move at a much lower velocity than the initial bullet?

A: Because the bullet's initial kinetic energy is distributed over the combined mass, resulting in a lower velocity due to conservation of momentum. The embedding process also dissipates a large amount of energy as heat and deformation, further reducing the final speed.

Q2: How does the inelastic nature of the collision affect energy conservation?

A: Inelastic collisions do not conserve kinetic energy; some energy is lost to internal deformation, heat, and sound. Only momentum is conserved during such impacts.

Q3: Can this analysis be applied to elastic collisions?

A: No, elastic collisions conserve both momentum and kinetic energy. The calculations would differ significantly in such cases.

Q4: What practical safety measures are based on understanding such impact dynamics?

A: Designing ballistic armor, crash barriers, and impact-absorbing materials rely heavily on understanding momentum transfer and energy dissipation during high-velocity impacts.

References and Further Reading

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- Impact Mechanics and Collision Dynamics, Physics Tutorials.

This detailed, SEO-structured article aims to provide clarity and depth on the physics of projectile embedding in a block, covering essential concepts, calculations, and practical applications to serve students, educators, and professionals alike.

Frequently Asked Questions

What is the initial momentum of the 16.2-g bullet traveling at 850 m/s?

The initial momentum is calculated by $p = m \times v$. Converting 16.2 g to kg (0.0162 kg), $p = 0.0162 \text{ kg} \times 850 \text{ m/s} \approx 13.77 \text{ kg}\cdot\text{m/s}$.

After the bullet embeds in the 40.0-kg block, what is the velocity of the combined system?

Using conservation of momentum: $m_{\text{bullet}} \times v_{\text{bullet}} = (m_{\text{bullet}} + m_{\text{block}}) \times v_{\text{final}}$. So, $v_{\text{final}} = (0.0162 \text{ kg} \times 850 \text{ m/s}) / (40.0 \text{ kg} + 0.0162 \text{ kg}) \approx 13.77 / 40.0162 \approx 0.344 \text{ m/s}$.

What is the amount of kinetic energy lost during the collision?

Initial KE = $0.5 \times 0.0162 \text{ kg} \times (850)^2 \approx 5,866 \text{ J}$. Final KE = $0.5 \times 40.0162 \text{ kg} \times (0.344)^2 \approx 2.37 \text{ J}$. Therefore, KE lost $\approx 5,866 \text{ J} - 2.37 \text{ J} \approx 5,863.63 \text{ J}$.

Is the collision elastic or inelastic, and why?

The collision is perfectly inelastic because the bullet embeds itself into the block, resulting in a combined mass moving with a common velocity, indicating kinetic energy is not conserved.

How would the velocity change if the block were attached to a spring instead of being free to move?

If attached to a spring, the block would oscillate after impact. The initial velocity would transfer into elastic potential energy stored in the spring, affecting the amplitude of oscillations rather than a simple translation.

What energy considerations are important in analyzing this impact scenario?

Key considerations include conservation of momentum during the inelastic collision and the transformation of kinetic energy into internal energy, deformation, or sound, with some energy lost as heat due to inelasticity.

Additional Resources

A 16.2-g Bullet With An Initial Speed Of 850 M/s Embeds Itself In A 40.0-kg Block, Which Is Attached — an intriguing scenario that combines principles of physics, conservation laws, and real-world applications. This problem encapsulates key concepts such as momentum, energy transfer, inelastic collisions, and the resulting motion of the combined system. Analyzing this situation provides insight into fundamental physics phenomena and their practical implications, from ballistics to engineering safety devices.

Introduction to the Scenario

The setup involves a small, high-velocity projectile (bullet) colliding with a substantially larger mass (block). The bullet's mass is 16.2 grams, which is 0.0162 kilograms, and it strikes the block at an

initial speed of 850 m/s. The block itself weighs 40.0 kg and is attached to some support or system that allows it to respond dynamically after the collision.

This type of problem is a classic example of inelastic collision physics, where the bullet embeds into the block, and the combined mass continues to move with a certain velocity post-collision. Understanding the behavior of such a system is not only academically interesting but also critically relevant in fields like ballistics, safety testing, and materials engineering.

Fundamental Concepts and Principles

Conservation of Momentum

The key principle at play in this problem is the conservation of linear momentum. Since external forces are assumed negligible during the very brief collision interval, the total momentum before impact equals the total momentum after impact:

$$p_{\text{initial}} = p_{\text{final}}$$

Mathematically:

$$m_b v_b = (m_b + m_{\text{block}}) v_{\text{final}}$$

where:

- m_b = mass of the bullet,
- v_b = initial velocity of the bullet,
- m_{block} = mass of the block,
- v_{final} = velocity of the combined system immediately after collision.

Inelastic Collision Dynamics

This collision is perfectly inelastic because the bullet embeds itself into the block, causing the two to move together afterward. Inelastic collisions are characterized by the loss of kinetic energy, which is transformed into deformation, heat, sound, and other forms of energy.

Energy Considerations

While momentum is conserved, kinetic energy is not necessarily conserved in inelastic collisions. The initial kinetic energy of the bullet is:

$$KE_{\text{initial}} = \frac{1}{2} m_b v_b^2$$

Post-collision, the combined kinetic energy is less, accounting for energy dissipated in the process.

Calculations and Analysis

Calculating the Final Velocity of the Embedded System

Using conservation of momentum:

$$v_{\text{final}} = \frac{m_b v_b}{m_b + m_{\text{block}}}$$

Plugging in the known values:

$$m_b = 0.0162 \text{ kg}$$

$$v_b = 850 \text{ m/s}$$

$$m_{\text{block}} = 40.0 \text{ kg}$$

Calculating:

$$v_{\text{final}} = \frac{0.0162 \times 850}{0.0162 + 40.0}$$

$$v_{\text{final}} \approx \frac{13.77}{40.0162}$$

$$v_{\text{final}} \approx 0.344 \text{ m/s}$$

This indicates that after embedding, the combined mass moves at approximately 0.344 meters per second, a relatively slow speed considering the initial velocity of the bullet.

Energy Loss During the Collision

Initial kinetic energy:

$$KE_{\text{initial}} = \frac{1}{2} \times 0.0162 \times (850)^2$$

$$KE_{\text{initial}} \approx 0.0081 \times 722,500$$

$$KE_{\text{initial}} \approx 5856 \text{ J}$$

Kinetic energy after the collision:

$$KE_{\text{final}} = \frac{1}{2} \times (m_b + m_{\text{block}}) \times v_{\text{final}}^2$$

$$KE_{\text{final}} = \frac{1}{2} \times 40.0162 \times (0.344)^2$$

$$KE_{\text{final}} \approx 20.0081 \times 0.118$$

$$KE_{\text{final}} \approx 2.37 \text{ J}$$

The energy lost:

$$\Delta KE = KE_{\text{initial}} - KE_{\text{final}} \approx 5856 - 2.37 \approx 5853.63 \text{ J}$$

This enormous energy dissipation highlights how inelastic collisions convert most of the initial

kinetic energy into heat, deformation, or sound.

Implications and Real-World Applications

Ballistics and Firearm Design

Understanding the energy transfer when a bullet embeds into a target is crucial for designing firearms, armor, and safety equipment. The calculated low velocity post-impact indicates how much the initial energy is dissipated, informing the design of protective gear that can absorb or deflect such energy.

Pros:

- Enables precise modeling of projectile behavior upon impact.
- Assists in optimizing materials for ballistic resistance.

Cons:

- Simplified models may not account for complex deformation behaviors.
- Real-world conditions involve additional factors like angle of impact, material properties, and environmental variables.

Material and Structural Engineering

The energy transfer and subsequent motion influence how structures respond to impacts, whether from projectiles, debris, or accidental collisions. Embedding phenomena can help predict damage thresholds and improve resilience.

Features:

- Informs the development of impact-resistant materials.
- Guides safety protocols in high-impact environments.

Safety and Testing

Controlled impact tests rely on understanding energy absorption and momentum transfer, ensuring safety standards are met in transportation, construction, and manufacturing.

Advantages:

- Quantitative data for safety certifications.
- Improved understanding of failure mechanisms.

Limitations:

- Laboratory conditions may differ from real-world complexities.
- Assumptions like perfect embedding may not always apply.

Further Considerations and Complexities

While the idealized calculation provides valuable insights, real-world scenarios involve additional factors:

- Material Deformation: Both the bullet and the block may deform, absorbing some energy.
- Friction and Air Resistance: External forces can influence the motion post-collision.
- Elastic Effects: Not all collisions are perfectly inelastic; some restitution could occur.
- Multiple Collisions: If the block is free to move or is attached via elastic supports, oscillations or other dynamic effects may arise.

In advanced physics and engineering, numerical simulations, finite element analysis, and experimental data supplement analytical calculations to produce more accurate predictions.

Conclusion

The scenario of a 16.2-g bullet traveling at 850 m/s embedding itself into a 40.0-kg block is a rich example demonstrating the fundamental principles of conservation of momentum and energy dissipation in inelastic collisions. The calculated post-impact velocity (~ 0.344 m/s) and the significant energy loss underscore the violent nature of such events and their importance in practical applications like ballistic armor design and impact testing.

Understanding these principles equips engineers and scientists to develop safer, more resilient systems, and deepens our appreciation of the complex interactions between objects during high-speed impacts. While idealized models provide clarity, integrating real-world complexities remains essential for accurate predictions and innovations.

In summary:

- The physics of embedding projectiles inform multiple industries.
- Conservation laws enable precise calculations of post-impact behavior.
- Energy dissipation highlights the destructive potential of high-velocity impacts.
- Continuous research and modeling improve safety and material performance in impact scenarios.

This detailed exploration underscores the importance of fundamental physics in solving practical problems and advancing technology across diverse fields.

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