A 50 Kg Skater At Rest On A Friction-less Rink Throws A 2 Kg Ball, Giving The Ball A Velocity Of 10 M/s.Which

Understanding the Physics Behind the Skater and Ball Scenario

A 50 Kg Skater At Rest On A Friction-less Rink Throws A 2 Kg Ball, Giving The Ball A Velocity Of 10 M/s. Which scenario involves fundamental principles of physics, particularly the conservation of momentum and Newton’s third law. This scenario is an excellent example to analyze how forces and motion interact in an isolated system, especially on a frictionless surface where external forces are negligible. In this article, we'll explore the physics concepts involved, perform calculations to understand the skater's recoil velocity, and discuss real-world applications of these principles.

The Core Concepts: Conservation of Momentum and Newton’s Laws

What Is Conservation of Momentum?

Conservation of momentum states that in a closed system with no external forces, the total momentum remains constant. When the skater throws the ball, the system's total momentum before and after the throw must be equal.

Newton’s Third Law of Motion

Newton’s third law states that for every action, there is an equal and opposite reaction. When the skater pushes the ball forward, the ball exerts an equal and opposite force on the skater, causing the skater to move backward.

Analyzing the Scenario Step-by-Step

Initial Conditions

- Mass of skater, $m_s = 50\,kg$
- Mass of ball, $m_b = 2\,kg$
- Initial velocities:
- Skater, $v_{s,i} = 0\,m/s$
- Ball, $v_{b,i} = 0\,m/s$

Post-Throw Conditions

- Ball velocity after throw: $v_{b,f} = 10\,m/s$
- Skater’s velocity after throw: $v_{s,f} = ?$

Calculating the Skater’s Recoil Velocity

Applying conservation of momentum:

$$
\text{Total initial momentum} = \text{Total final momentum}
$$

$$
m_s \times v_{s,i} + m_b \times v_{b,i} = m_s \times v_{s,f} + m_b \times v_{b,f}
$$

Since both start at rest:

$$
0 = 50 \times v_{s,f} + 2 \times 10
$$

$$
0 = 50 \times v_{s,f} + 20
$$

Solving for $v_{s,f}$:

$$
v_{s,f} = - \frac{20}{50} = -0.4\,m/s
$$

Interpretation:
- The negative sign indicates that the skater moves in the opposite direction to the thrown ball.
- The skater’s recoil velocity is 0.4 m/s in the direction opposite to the ball's motion.

Implications of the Recoil Velocity

Energy Considerations

Since the surface is frictionless, no external energy is lost due to friction. The energy transferred from the skater to the ball manifests as kinetic energy of the ball and the skater's recoil:

$$
\text{Kinetic energy of ball} = \frac{1}{2} m_b v_{b}^2 = \frac{1}{2} \times 2 \times 10^2 = 100\,J
$$

$$
\text{Kinetic energy of skater} = \frac{1}{2} m_s v_{s}^2 = \frac{1}{2} \times 50 \times (0.4)^2 = 4\,J
$$

Total kinetic energy after the throw:

$$
100\,J + 4\,J = 104\,J
$$

This energy is derived from the skater’s muscles — the act of throwing transfers energy to the ball, and the skater recoils with a small velocity.

Real-World Applications

Understanding these principles is crucial in various fields:
- Spacecraft propulsion: Using momentum conservation to propel spacecraft without external forces.
- Sports physics: Analyzing techniques in throwing or hitting objects.
- Engineering: Designing systems that rely on recoil, such as recoilless rifles or certain rocket designs.

Further Considerations and Variations

Effect of External Forces

In real-world scenarios, factors like air resistance, friction, and external forces can alter the results. Here, assuming a frictionless surface simplifies the calculations.

Changing the Variables

- If the ball had a different velocity upon being thrown, how would that affect the skater's recoil?
- What if the mass of the skater or the ball changed? How would that influence the velocities?

Sample Calculations for Variations

Suppose the ball is thrown at 15 m/s instead of 10 m/s:

$$
0 = 50 v_{s,f} + 2 \times 15 = 50 v_{s,f} + 30
$$

$$
v_{s,f} = - \frac{30}{50} = -0.6\,m/s
$$

The skater recoils faster (0.6 m/s) when the ball is thrown at a higher velocity.

Conclusion: The Importance of Momentum Conservation in Physics

This scenario beautifully illustrates fundamental physics principles. The conservation of momentum ensures that when the skater throws the ball, both objects react according to their masses and velocities, preserving the total momentum of the system. The skater's recoil velocity, calculated to be 0.4 m/s in the opposite direction, is a direct consequence of these principles.

Understanding these concepts is not only academically interesting but also practically significant in designing and analyzing systems involving motion and forces. Whether in sports, engineering, or space exploration, mastering the physics of recoil and momentum transfer enables better design, strategy, and innovation.

Additional Resources for Further Learning

- Newton’s Laws of Motion: Fundamental principles governing motion.
- Conservation of Momentum: In-depth explanations and problem-solving techniques.
- Kinetic Energy and Work: How energy transfer relates to motion.
- Real-World Applications: Case studies involving recoil and momentum transfer.

By mastering these concepts, students and professionals alike can develop a deeper appreciation of the elegant and powerful laws that govern the physical world.

Frequently Asked Questions

What is the principle behind the skater's recoil when throwing the ball?

The principle is conservation of momentum; since no external forces act horizontally, the total momentum before and after the throw remains zero, causing the skater to move backward when the ball is thrown forward.

How fast does the skater move backward after throwing the ball?

Using conservation of momentum: (mass of skater × velocity of skater) + (mass of ball × velocity of ball) = 0. Therefore, velocity of skater = -(mass of ball × velocity of ball) / mass of skater = -(2 kg × 10 m/s) / 50 kg = -0.4 m/s. The skater moves backward at 0.4 m/s.

Why is the initial momentum of the system zero?

Because the skater is initially at rest and no external horizontal forces are acting on the system, so the total initial momentum is zero.

What is the significance of the rink being frictionless in this scenario?

The frictionless surface ensures that no external horizontal forces oppose the skater's movement, making conservation of momentum directly applicable without energy loss due to friction.

How does the mass of the skater affect their recoil velocity after throwing the ball?

The recoil velocity is inversely proportional to the skater's mass; a heavier skater will move backward more slowly than a lighter one when throwing the same ball at the same speed.

If the skater throws the ball at a higher velocity, how does that affect the skater's recoil speed?

Increasing the ball's velocity increases the magnitude of the skater's recoil speed proportionally, as per conservation of momentum: higher ball velocity results in greater backward recoil of the skater.

Can the skater use this principle to propel themselves across the ice?

Yes, by throwing objects backward, the skater can gain forward momentum and propel themselves across the ice, similar to how astronauts use action-reaction forces in space.

What assumptions are made in calculating the skater's recoil velocity?

Assumptions include a frictionless surface, no external forces, the system is isolated, and the mass and velocity of the ball are known and initial momentum is zero.

Additional Resources

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Introduction

The scenario of a skater at rest on a frictionless rink throwing a ball presents a classic application of the principles of conservation of momentum and Newtonian mechanics. Although seemingly straightforward, this scenario offers rich insights into the dynamics of isolated systems, the transfer of momentum, and the resulting motion of both objects involved. This investigation delves deeply into the physics underlying the interaction between the skater and the ball, analyzing the consequences of the throw, and exploring the broader implications of such a seemingly simple act within the framework of classical mechanics.

Background and Theoretical Foundations

Conservation of Momentum

At the core of this problem lies the law of conservation of momentum, which states that in an isolated system with no external forces, the total momentum remains constant over time. For a skater and a ball initially at rest, the total initial momentum is zero. When the skater throws the ball, the momentum gained by the ball must be offset by an equal and opposite momentum imparted to the skater, ensuring the total momentum remains zero.

Mathematically, this principle is expressed as:

$$
\textbf{Initial total momentum} = \textbf{Final total momentum}
$$

$$
0 = m_{s} \times v_{s} + m_{b} \times v_{b}
$$

where:
- m_{s} = mass of the skater = 50 kg
- v_{s} = velocity of the skater after the throw (unknown)
- m_{b} = mass of the ball = 2 kg
- v_{b} = velocity of the ball after the throw = 10 m/s

Newton’s Third Law and Action-Reaction Forces

The act of throwing involves internal forces. When the skater pushes the ball, the force exerted on the ball has an equal and opposite reaction force exerted on the skater. In a frictionless environment, these internal forces result in the skater moving backward after the throw, in accordance with Newton’s third law.

Quantitative Analysis of the Throw

Calculating the Skater's Recoil Velocity

Using conservation of momentum:

$$
0 = m_{s} \times v_{s} + m_{b} \times v_{b}
$$

Rearranged:

$$
v_{s} = - \frac{m_{b} \times v_{b}}{m_{s}}
$$

Substituting known values:

$$
v_{s} = - \frac{2\, \text{kg} \times 10\, \text{m/s}}{50\, \text{kg}} = -
\frac{20}{50} = -0.4\, \text{m/s}
$$

The negative sign indicates that the skater moves in the opposite direction to the ball's motion, with a velocity of 0.4 m/s.

Interpretation of Results

- The skater, initially at rest, gains a velocity of 0.4 m/s in the opposite direction of the ball's throw.
- The ball, now moving at 10 m/s, carries a significant fraction of the momentum imparted during the throw.
- The total kinetic energy after the throw is:

$$
K_{total} = \frac{1}{2} m_{b} v_{b}^2 + \frac{1}{2} m_{s} v_{s}^2
$$

Calculating:

$$
K_{ball} = \frac{1}{2} \times 2\, \text{kg} \times (10\, \text{m/s})^2 = 100\, \text{J}
$$

$$
K_{skater} = \frac{1}{2} \times 50\, \text{kg} \times (0.4\, \text{m/s})^2 = 4\, \text{J}
$$

Total kinetic energy:

$$
K_{total} = 104\, \text{J}
$$

This reveals that the kinetic energy of the system increases post-throw, which suggests that in real-world scenarios, additional energy input (e.g., muscular work) is involved in the act of throwing.

Broader Implications and Applications

Momentum and Energy Transfer in Isolated Systems

This scenario exemplifies how internal forces redistribute energy and momentum within an isolated system. It illustrates that:

- The total momentum remains conserved.
- The energy invested in the throw is partitioned between the kinetic energies of the ball and the skater.
- The energy transfer involves internal work, which accounts for the increase in kinetic energy.

Practical Applications in Sports and Engineering

Understanding such mechanics has practical relevance:

- Sports Science: Athletes leverage these principles when throwing or pushing objects, optimizing their technique to maximize force while minimizing recoil.
- Robotics and Mechanical Systems: Engineers design systems where internal mass movement or force application results in controlled motion, such as in reaction wheels of spacecraft or self-propelling robots.
- Conservation Laws in Design: Recognizing the conservation of momentum helps in designing safer, more efficient vehicles and machinery that rely on internal mass reconfiguration.

Limitations and Assumptions

This analysis relies on several idealizations:

- Frictionless Environment: In reality, friction and air resistance dissipate energy, making the actual velocities slightly different.
- Perfectly Inelastic System: No external forces act on the system; in practice, external forces like gravity or air resistance influence the motion.
- Instantaneous Momentum Transfer: The calculation assumes an instantaneous throw, ignoring the dynamics of muscle force application and acceleration phases.

Further, the energy calculations underscore that the act of throwing requires an external energy input—muscular effort—highlighting the importance of internal work in changing the system's energy state.

Conclusion

The simple act of a skater throwing a ball encapsulates fundamental principles of physics, notably conservation of momentum and energy transfer. The skater, initially at rest, acquires a recoil velocity of 0.4 m/s in the opposite direction of the throw, balancing the momentum imparted to the ball moving at 10 m/s. The analysis not only underscores the elegant symmetry of Newtonian mechanics but also emphasizes the importance of understanding internal forces and energy dynamics in practical applications ranging from sports to engineering.

This case study demonstrates that even a straightforward action such as throwing a ball on a frictionless rink embodies complex physical interactions, reinforcing the importance of fundamental physics in analyzing and optimizing real-world systems.

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