Q/C A 65.0-kg Boy And His 40.0-\mathrm{kg} Sister, Both Wearing Roller Blades, Face Each Other At Rest.

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Introduction

Imagine a sunny afternoon at a bustling skate park. A 65.0-kg boy and his 40.0-kg sister are standing face-to-face, both wearing roller blades. They are initially at rest, engaging in a playful moment before starting to glide across the concrete. This scenario, though simple at first glance, offers a fascinating insight into the principles of physics—specifically, Newton’s laws of motion, conservation of momentum, and the effects of internal forces on a system at rest.

Understanding how these two individuals interact on their roller blades, especially when they push off or shift their weight, reveals the fundamental concepts of internal and external forces, center of mass, and how action and reaction forces operate in real-world situations. This article aims to analyze the physics involved in this scenario comprehensively, making it accessible to students, educators, and physics enthusiasts alike.

Context and Relevance of the Scenario

The scenario of a boy and his sister standing face-to-face on roller blades is not only relatable but also serves as an excellent practical example for studying mechanics. It demonstrates:

- Conservation of Momentum: How internal forces within a system do not change the total momentum unless external forces act.
- Center of Mass Dynamics: How the position and movement of the system's center of mass influence the motion.
- Force Interaction: How action and reaction forces operate during pushing and balancing on roller blades.

By analyzing this situation, we can better understand how athletes, dancers, and even astronauts manage motion and balance. It also helps clarify common misconceptions about motion, such as the idea that pushing against each other would cause either person to move significantly or remain stationary.

Fundamental Physics Principles Involved

Newton’s Laws of Motion

- First Law (Inertia): An object at rest stays at rest unless acted upon by an external force.
- Second Law (F = ma): The acceleration of an object depends on the net external force applied and its mass.
- Third Law (Action-Reaction): For every action, there is an equal and opposite reaction.

Conservation of Momentum

In an isolated system with no external forces, the total momentum remains constant. When the boy and sister push against each other, their internal forces change their individual momenta, but the total momentum of the system remains zero if initially at rest.

Center of Mass

The center of mass (COM) of a system is the point where the entire mass can be considered to be concentrated for analyzing translational motion. For the boy-sister system, the COM's position and movement are crucial in understanding their motions after pushing off.

Analyzing the Scenario: Step-by-Step

Initial Conditions

- Both are facing each other, at rest.
- Mass of boy, $m_b = 65.0\, \mathrm{kg}$
- Mass of sister, $m_s = 40.0\, \mathrm{kg}$
- Initial velocities: $v_{b,i} = 0$, $v_{s,i} = 0$

Action: The Push-Off

Suppose the boy and sister push against each other with equal and opposite forces. According to Newton’s third law, these forces are equal in magnitude but opposite in direction.

Resulting Motion

- The boy will move backward with velocity v_b.
- The sister will move forward with velocity v_s.

Because no external horizontal forces are acting (assuming negligible friction), their momenta after pushing will satisfy:

$$
m_b v_b + m_s v_s = 0
$$

This equation indicates that the total momentum of the system remains zero, consistent with conservation of momentum.

Calculating Final Velocities

From the momentum equation:

$$
m_b v_b = - m_s v_s
$$

Assuming the magnitude of the force and the duration of push are such that the impulses are equal:

$$
v_b = - \frac{m_s}{m_b} v_s
$$

The velocities are inversely proportional to their masses:

$$
v_b = - \frac{40.0\, \mathrm{kg}}{65.0\, \mathrm{kg}} v_s \approx -0.615 v_s
$$

The negative sign indicates opposite directions.

Conservation of Center of Mass

The position of the center of mass before and after the push remains the same, assuming no external forces. The initial position:

$$
X_{COM,i} = \frac{m_b x_{b,i} + m_s x_{s,i}}{m_b + m_s}
$$

Since they face each other at rest, the initial positions are arbitrary but fixed, say:

- $x_{b,i} = 0$
- $x_{s,i} = d$

The initial COM:

$$
X_{COM,i} = \frac{65.0 \times 0 + 40.0 \times d}{105.0}
$$

After pushing, their positions change:

- $x_b' = x_b + v_b t$
- $x_s' = x_s + v_s t$

The center of mass position after the push:

$$
X_{COM,f} = \frac{m_b x_b' + m_s x_s'}{m_b + m_s}
$$

Since no external forces act, $X_{COM,f} = X_{COM,i}$. This allows us to analyze their velocities and confirm the conservation of momentum.

Practical Implications and Real-World Applications

Balance and Motion Control in Sports

Understanding how mass and force interactions influence motion helps athletes optimize their techniques. For example, roller skaters, ice skaters, and dancers rely on internal forces to initiate movement without external pushes.

Safety Considerations

Knowing that internal pushes cause movement while the system's overall momentum remains conserved can inform safety protocols, especially when children or beginners learn to avoid unintended falls or collisions.

Engineering and Robotics

Designing systems where internal forces generate motion—such as robots or automated vehicles—requires understanding these physics principles to ensure stability and control.

Additional Factors Affecting Motion

While the idealized analysis assumes negligible friction and perfect force application, real-world factors include:

- Friction: Between roller blades and the ground, which opposes motion.
- Air Resistance: Slight but becomes relevant at higher speeds.
- Distribution of Force: How force is applied during pushing affects acceleration.
- Body Mechanics: Posture and balance influence the efficiency of motion.

In practice, these factors can influence the velocities achieved and the ease of movement after pushing.

Conclusion

The scenario of a 65.0-kg boy and his 40.0-kg sister facing each other on roller blades exemplifies several foundational physics principles. From the conservation of momentum to the dynamics of internal forces, analyzing their interaction offers valuable insights into motion and balance.

By understanding that internal forces like pushes cause movement within the system but do not alter the total momentum, learners can better grasp how objects and systems behave in real life. Whether in sports, engineering, or everyday activities, these principles underpin much of the physical world around us.

Keywords for SEO Optimization

- Physics of roller blades
- Conservation of momentum in skating
- Internal and external forces
- Center of mass analysis
- Newton’s laws in motion
- Dynamics of pushing on roller skates
- Motion analysis in sports
- Physics problems involving internal forces
- Balance and motion in skating
- Real-world physics examples

Frequently Asked Questions

What is the initial state of the boy and sister in the scenario?

Both the boy and his sister are initially at rest, facing each other while wearing roller blades.

Why do the boy and sister face each other while at rest on roller blades?

They are likely preparing for a skating interaction or demonstration, and their facing each other allows for interaction or potential movement toward each other.

What happens when the boy and sister push off against each other on roller blades?

According to Newton's third law, when they push against each other, they exert equal and opposite forces, causing both to accelerate in opposite directions.

How can we calculate the velocities of the boy and sister after they push off each other?

Using conservation of momentum, the total initial momentum is zero, so the sum of their momenta after pushing off must also be zero, allowing calculation of their velocities based on their masses.

What is the significance of their masses in analyzing their motion after pushing off?

The masses determine how the forces translate into accelerations and velocities, with the heavier person experiencing smaller velocity changes compared to the lighter one, according to Newton's second law.

If the boy pushes off with a certain force, how does that affect his velocity compared to his sister’s?

Given equal and opposite forces, the lighter sister will attain a higher velocity change than the heavier boy, meaning she will move faster in the opposite direction.

What role does conservation of momentum play in this scenario?

Conservation of momentum ensures that the total momentum before and after pushing off remains zero, dictating the velocities and directions of both the boy and sister after the push.

How does understanding this scenario help in learning about Newton's third law and conservation principles?

It provides a practical example of action-reaction forces and how momentum is conserved in isolated systems, reinforcing core physics concepts through real-world motion.

Additional Resources

Q/C A 65.0-kg Boy And His 40.0-kg Sister, Both Wearing Roller Blades, Face Each Other At Rest — this scenario presents an intriguing opportunity to explore fundamental principles of physics, particularly Newton’s laws of motion, conservation of momentum, and the dynamics of forces during interaction. Imagine a boy and his sister standing face-to-face on roller blades, both initially at rest. When they push off against each other, how do their masses and the forces involved influence their subsequent motion? Understanding this scenario not only deepens our grasp of mechanics but also highlights real-world applications like skating, sports, and safety considerations.

Introduction: Setting the Stage

In everyday life, interactions involving forces and motion are ubiquitous. A classic physics problem involves two individuals on roller blades facing each other, initially at rest, then pushing off to move apart. This scenario illustrates Newton’s third law — for every action, there is an equal and opposite reaction — and demonstrates how momentum is conserved in isolated systems.

Key details:
- Boy’s mass: 65.0 kg
- Sister’s mass: 40.0 kg
- Both initially at rest
- Facing each other on roller blades

The question: When they push off, how do their velocities change? How does mass influence their acceleration? And what role does the force they exert play? To answer these, we’ll systematically analyze the physics involved.

Fundamental Concepts Underpinning the Scenario

Before delving into calculations, it’s essential to revisit some core physics principles:

Newton’s Laws of Motion
- First Law: An object remains at rest or in uniform motion unless acted upon by an external force.
- Second Law: $F = ma$, where F is force, m is mass, and a is acceleration.
- Third Law: For every action, there is an equal and opposite reaction.

Conservation of Momentum
In an isolated system (no external horizontal forces), the total momentum before and after an interaction remains constant:
$$
\text{Initial total momentum} = \text{Final total momentum}
$$

Since the initial momentum of the boy and sister is zero (both at rest), the total momentum after they push off must also be zero.

Analyzing the Push-Off: Step-by-Step Breakdown

Let’s model the interaction as follows:

- Initial state: Both are at rest, facing each other.
- Action: They push against each other with equal and opposite forces.
- Outcome: They move in opposite directions with velocities v_b (boy) and v_s (sister).

Step 1: Applying Conservation of Momentum

Since the system is initially at rest, the total momentum after pushing off must be zero:
$$
m_b v_b + m_s v_s = 0
$$
where:
- $m_b = 65.0\, \mathrm{kg}$,
- $m_s = 40.0\, \mathrm{kg}$,
- v_b and v_s are their velocities after pushing.

Rearranged,
$$
m_b v_b = - m_s v_s
$$
which indicates they move in opposite directions; if the boy moves forward, the sister moves backward, or vice versa.

Calculating Velocities Post Push

Assuming they exert the same magnitude of force during push-off, the accelerations depend inversely on their masses (from $F = ma$). The force they exert on each other is equal and opposite (Newton's third law).

Step 2: Relationship Between Velocities

From conservation of momentum:

$$
v_b = - \frac{m_s}{m_b} v_s
$$

Suppose we want to find the velocities after a certain push force or impulse. To do so, we need to consider the impulse-momentum theorem.

Impulse and Force Duration: Connecting Force to Velocity

The impulse-momentum theorem states:

$$
F \Delta t = m \Delta v
$$

where:
- F is the average force exerted during push-off,
- Δt is the duration of contact,
- Δv is the change in velocity.

Assuming the force exerted during push-off is F, acting over a small time Δt, we can write:

$$
m_b v_b = F \Delta t
$$

and similarly for the sister:

$$
m_s v_s = -F \Delta t
$$

since the forces are equal and opposite.

Therefore:

$$
v_b = \frac{F \Delta t}{m_b}
\quad \text{and} \quad
v_s = - \frac{F \Delta t}{m_s}
$$

Using the earlier momentum relation:

$$
m_b v_b = - m_s v_s
$$

which is consistent.

Numerical Example: Estimating Velocities

Suppose the force exerted during push-off is approximately 50 N (a reasonable estimate for a human push on roller blades), and the push lasts about 0.2 seconds.

Calculate velocities:

$$
v_b = \frac{F \Delta t}{m_b} = \frac{50\, \mathrm{N} \times 0.2\, \mathrm{s}}{65.0\, \mathrm{kg}} \approx \frac{10\, \mathrm{N\cdot s}}{65.0\, \mathrm{kg}} \approx 0.154\, \mathrm{m/s}
$$

Similarly,

$$
v_s = - \frac{50\, \mathrm{N} \times 0.2\, \mathrm{s}}{40.0\, \mathrm{kg}} = - \frac{10\, \mathrm{N\cdot s}}{40.0\, \mathrm{kg}} = -0.25\, \mathrm{m/s}
$$

Interpretation:
- The boy moves forward at approximately 0.154 m/s.
- The sister moves backward at approximately 0.25 m/s.

Note how the mass influences their velocities; the lighter sister gains a higher speed.

Momentum Conservation Check

Verify that total momentum is zero:

$$
m_b v_b + m_s v_s = 65.0 \times 0.154 + 40.0 \times (-0.25) \approx 10.0 - 10.0 = 0
$$

which confirms the calculations align with the law of conservation of momentum.

Energy Considerations

While the problem primarily involves momentum, it's interesting to consider the energy involved:

$$
\text{Kinetic energy} = \frac{1}{2} m v^2
$$

Calculations:

- Boy:
$$
KE_b = \frac{1}{2} \times 65.0\, \mathrm{kg} \times (0.154)^2 \approx 0.77\, \mathrm{J}
$$

- Sister:
$$
KE_s = \frac{1}{2} \times 40.0\, \mathrm{kg} \times (0.25)^2 \approx 1.25\, \mathrm{J}
$$

Total kinetic energy gained during push:

$$
KE_{total} \approx 0.77 + 1.25 \approx 2.02\, \mathrm{J}
$$

This illustrates how mechanical work done by the force results in kinetic energy, with the lighter sister gaining more velocity and kinetic energy relative to her mass.

Practical Insights and Safety Considerations

Understanding these physics principles is crucial for real-world safety and performance:

- Mass impacts velocity: The lighter individual (sister) gains higher speed for the same push force.
- Control and stability: Both should push gently to avoid losing balance or colliding.
- Energy transfer: The push transfers energy into motion, which, if uncontrolled, could lead to falls or injuries.

Extending the Analysis: Variations and Additional Factors

In real-life scenarios, several factors influence the outcome:

- Friction and rolling resistance: Surface conditions and skate quality affect how motion develops.
- Force application: The force might vary during push, and not all energy converts efficiently into kinetic energy.
- External forces: Wind or uneven surfaces introduce external forces, complicating the conservation assumptions.
- Initial conditions: If the initial stance isn't perfectly balanced, initial torque could introduce rotation.

Summary and Key Takeaways

- When a boy and his sister face each other on roller blades and push off, their velocities are inversely proportional to their masses, assuming equal and opposite forces.
- The conservation of momentum dictates that the total momentum after push-off remains zero, resulting in movement in opposite directions.

- The lighter individual (sister) attains a higher velocity for the same force, illustrating the inverse relationship between mass and velocity.
- Calculations based on impulse and force duration can approximate their velocities, providing insight into the forces involved during push-off.
- Real-world applications include understanding skating dynamics, designing safety equipment, and analyzing sports movements.

Final Thoughts

This scenario encapsulates fundamental physics principles in a relatable context. Whether you're a student tackling homework problems or a skating enthusiast, appreciating how mass, force, and momentum interplay enhances both understanding and safety. Remember, the elegance of physics lies in its ability to describe everyday phenomena with clarity and precision. Next time you see skaters push off or players collide, think about the unseen

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