A Hockey Puck With Mass 0.160 Kg Is At Rest At The Origin (x = 0) On The Horizontal Frictionless Surface

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Understanding the physics of motion on frictionless surfaces provides fundamental insights into classical mechanics. In this article, we explore the scenario involving a hockey puck with a mass of 0.160 kg initially at rest at the origin (x=0) on a frictionless horizontal surface. We analyze how various forces, initial conditions, and potential external influences affect its motion, acceleration, and kinetic energy. This comprehensive guide aims to clarify the concepts for students, educators, and physics enthusiasts interested in the mechanics of objects in idealized conditions.

Introduction to the Problem

The situation involves a hockey puck—an object commonly encountered in sports and physics experiments—placed on a flat, frictionless surface. It is initially at rest at the coordinate origin, meaning its initial position is x=0. The key parameters include:

- Mass of the puck (m): 0.160 kg
- Initial position (x_0): 0
- Initial velocity (v_0): 0 (at rest)
- Surface: Horizontal and frictionless

This setup provides an idealized environment to study fundamental principles such as Newton's laws, work-energy theorem, and the effects of external forces.

Fundamental Concepts in Motion on Frictionless Surfaces

Newton's Second Law

The core principle governing the motion of the puck is Newton's second law:

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

where:

- F_{net} is the net external force applied to the puck
- m is the mass of the puck
- a is its acceleration

In the absence of friction and other resistive forces, the puck's behavior depends solely on the external forces applied.

Frictionless Surface Assumption

A frictionless surface implies that:

- No resistive force opposes the puck's motion
- The only forces acting are those intentionally applied or gravity (which acts perpendicular to the surface and does not affect horizontal motion)

This simplifies analysis because once the puck is set into motion, it will continue moving at a constant velocity unless acted upon by an external force.

Analyzing the Motion of the Hockey Puck

Initial Conditions

Since the puck is initially at rest:

- Velocity $v_{i} = 0$
- Position $x_{i} = 0$

Any subsequent motion depends on external forces or initial impulses.

Applying External Force

Suppose an external force F is applied to the puck:

- If F is constant, the acceleration a is constant:

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

- The motion equations for constant acceleration are:

$$ v = v_{i} + a t $$

$$ x = x_{i} + v_{i} t + \frac{1}{2} a t^{2} $$

Given initial conditions ($v_{i} = 0, x_{i} = 0$):

$$ v(t) = \frac{F}{m} t $$

$$ x(t) = \frac{1}{2} \frac{F}{m} t^{2} $$

This indicates that the puck accelerates uniformly under a constant force.

Scenario 1: No External Force

If no external force is applied after the initial state, the puck remains at rest indefinitely, moving with zero velocity due to Newton's first law:

- Constant velocity motion: the puck continues at rest forever
- Implication: The initial state is static, and the puck remains at rest unless an external force acts

Scenario 2: Impulse Force Applied

Applying an impulse J (force applied over a short time Δt) changes the puck's momentum:

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

The change in velocity:

$$ \Delta v = \frac{J}{m} $$

- If a quick push is applied, the puck gains a velocity:

$$ v_{f} = \frac{J}{m} $$

- It then continues to move at constant velocity due to the frictionless surface.

Energy Considerations

Kinetic Energy of the Puck

The kinetic energy (KE) of the puck when it's in motion:

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

- Initially, KE = 0 (at rest)
- After applying a force or impulse, KE becomes:

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

which increases with the velocity imparted.

Work-Energy Theorem

Work done by external forces equals the change in kinetic energy:

$$ W = \Delta KE $$

- For a constant force F over displacement x:

$$ W = F \times x $$

- Since the surface is frictionless, no energy is lost to heat or resistance.

External Influences and Real-World Applications

Practical Applications

Understanding the behavior of a puck on a frictionless surface has applications in:

- Ice hockey: real-world scenarios involve low friction, and understanding puck dynamics aids in strategy and equipment design.
- Physics experiments: simulating ideal conditions to study fundamental laws without resistive forces.
- Educational demonstrations: illustrating concepts of Newton's laws, energy, and momentum.

External Forces in Real-Life Situations

In real applications, factors such as air resistance, friction, and external impacts influence motion. However, the ideal models assume a frictionless surface to focus on pure physics principles.

Mathematical Examples and Problem-Solving Approaches

Example 1: Applying a Known Force

Suppose a force of 2 N is applied to the puck for 0.5 seconds:

- Impulse:

$$ J = F \times \Delta t = 2 \times 0.5 = 1\, \text{Ns} $$

- Change in velocity:

$$ \Delta v = \frac{J}{m} = \frac{1}{0.160} \approx 6.25\, \text{m/s} $$

- Final velocity:

$$ v_{f} = 6.25\, \text{m/s} $$

- Displacement during force application:

$$ x = v_{i} t + \frac{1}{2} a t^{2} $$

Since initial velocity is zero:

$$ a = \frac{F}{m} = \frac{2}{0.160} = 12.5\, \text{m/s}^2 $$

$$ x = 0 + \frac{1}{2} \times 12.5 \times (0.5)^2 = 0.5 \times 12.5 \times 0.25 = 1.5625\, \text{m} $$

Thus, during the application of force, the puck moves approximately 1.56 meters.

Example 2: No External Force After Initial Push

If the puck is pushed to reach a velocity of 3 m/s and then left alone:

- Its subsequent motion:

$$v = 3\, \text{m/s}$$

- It will continue at this constant velocity indefinitely on the frictionless surface.

Summary and Key Takeaways

- The motion of a hockey puck on a frictionless surface is governed by Newton's laws, accelerations, and energy principles.
- Without external forces, the puck remains at rest or moves with constant velocity.
- External forces or impulses change the puck's velocity, which then remains constant due to the absence of friction.
- Energy transfer in ideal conditions involves no loss; kinetic energy depends on the velocity imparted.
- Practical applications of this physics model include sports science, experimental physics, and educational demonstrations.

Conclusion

Analyzing a hockey puck with a mass of 0.160 kg at rest on a frictionless surface provides a clear understanding of fundamental mechanics. Whether examining the effects of external forces, impulses, or energy transfer, this scenario exemplifies the core principles that govern motion in idealized conditions. Mastery of these concepts lays the foundation for more complex studies in physics, including real-world applications where resistive forces are minimal or can be approximated as negligible.

By understanding the behavior of objects like hockey pucks in frictionless environments, students and enthusiasts can deepen their comprehension of motion, energy, and the laws that describe our physical universe.

Frequently Asked Questions

What is the initial velocity of the hockey puck at rest?

The initial velocity of the hockey puck is 0 m/s since it is at rest.

If a force is applied to the puck, how will its acceleration be calculated?

The acceleration can be calculated using Newton's second law: $a = F / m$, where F is the applied force and m is the mass of the puck (0.160 kg).

What is the significance of a frictionless surface in this scenario?

A frictionless surface means there is no opposing force due to friction, so the puck's motion will only change if an external force is applied, conserving its momentum.

How does the conservation of momentum apply to the puck on a frictionless surface?

Since no external horizontal forces are acting, the total momentum of the puck remains constant, meaning if it starts at rest, it will stay at rest unless acted upon by an external force.

What would happen if an impulse is applied to the puck?

Applying an impulse would change the puck's momentum, resulting in a change in its velocity according to the impulse-momentum theorem: $J = \Delta p$.

How can the velocity of the puck be determined after applying a force over a certain time?

The velocity can be found using the impulse-momentum theorem: $v = (F \times \Delta t) / m$, where F is the force, Δt is the duration, and m is the mass.

What is the kinetic energy of the puck if it is given a certain velocity?

The kinetic energy is given by KE = (1/2) m v^2, where m is 0.160 kg and v is the velocity after force application.

Can the puck move on a frictionless surface without any applied force?

No, if the puck is initially at rest and no external forces act upon it, it will remain at rest due to inertia.

How does the mass of the puck affect its response to an applied force?

A larger mass results in a smaller acceleration for the same applied force, as per Newton's second law (a = F / m).

What real-world applications can be related to the motion of a hockey puck on a frictionless surface?

This scenario models idealized conditions similar to ice hockey, where players aim to minimize friction to allow the puck to glide smoothly, and it also relates to principles in physics simulations and game design.

Additional Resources

A Hockey Puck With Mass 0.160 Kg Is At Rest At The Origin (x = 0) On The Horizontal Frictionless Surface

In the realm of classical mechanics, the motion of objects under various forces offers a rich landscape for exploration and understanding. A common yet insightful scenario involves a hockey puck, a simple yet effective model for studying translational motion, especially when placed on an ideal surface. Consider a hockey puck with a mass of 0.160 kg initially at rest at the origin (x=0) on a horizontal, frictionless surface. This setup provides a foundational context to examine fundamental principles such as Newton's laws, conservation of momentum, and energy, as well as the effects of external forces. This article delves into the details of this scenario, exploring the physics behind it with clarity and depth, and analyzing the implications of various forces and conditions that could influence the puck's motion.

Setting the Stage: The Physical System

Characteristics of the Hockey Puck

The hockey puck, a cylindrical object, is widely used in ice hockey due to its low friction and smooth surface. In physics, it serves as an idealized model because of its uniform mass distribution and simple shape. The key properties relevant to our analysis include:

- Mass (m): 0.160 kg—a typical mass for a standard hockey puck.
- Initial position: At the origin (x=0), indicating its starting point in a coordinate system.
- Initial velocity: At rest, so initial velocity v_0 = 0 m/s.

- Shape and surface: Flat, smooth, and on a frictionless horizontal surface, eliminating resistive forces like friction.

This idealized setup simplifies the analysis, focusing purely on the effects of external forces and initial conditions without the complicating influence of friction or air resistance.

Why a Frictionless Surface Matters

Friction is a resistive force that opposes motion, converting kinetic energy into heat. By assuming a frictionless surface, the model isolates the effects of other forces such as applied pushes, gravity (which acts perpendicular to the surface and thus doesn't influence horizontal motion), or external impulses. This idealization allows physicists and students to understand the fundamental principles of motion, energy conservation, and momentum transfer without the confounding influence of frictional forces.

Fundamental Principles Governing the System

Newton's Laws of Motion

The core of classical mechanics, Newton's Laws, provide the framework for analyzing the puck's behavior:

1. First Law (Inertia): An object at rest remains at rest unless acted upon by an external force.
2. Second Law (F=ma): The acceleration of the object is directly proportional to the net external force and inversely proportional to its mass.
3. Third Law: For every action, there is an equal and opposite reaction.

In our scenario, since the puck starts at rest and on an ideal surface, any change in motion hinges on external forces applied.

Conservation Laws

Two pivotal conservation principles come into play:

- Conservation of Momentum: In the absence of external forces, the total momentum of the system remains constant.

- Conservation of Energy: With no dissipative forces like friction, kinetic energy remains constant if no work is done by external forces.

These principles help predict how the puck will behave under various force applications, such as pushes, hits, or impacts.

Analyzing Different Force Scenarios

The motion of the puck depends on the external forces acting upon it. Let's explore some common scenarios:

Scenario 1: No External Forces (Equilibrium)

Since the puck starts at rest and no external forces act on it, Newton's First Law dictates that it will remain stationary indefinitely. Its velocity remains zero, and there is no acceleration or change in position. This ideal situation underscores the importance of external influence for motion to occur.

Scenario 2: Applying a Constant Force

Suppose an external agent applies a constant horizontal force (F) to the puck. The analysis involves:

- Acceleration Calculation:
Using Newton's Second Law,
$a = F/m$.

- Motion Over Time:
Starting from rest, the velocity after time t is:
$v(t) = a\,t = (F/m)\,t$.

- Displacement:
The distance traveled after time t is:
$x(t) = (1/2)\,a\,t^2 = (1/2)\,(F/m)\,t^2$.

Implication:
The puck accelerates uniformly, gaining speed linearly over time, and covers a quadratic distance. Because the surface is frictionless, the puck will continue to accelerate as long as the force is applied, illustrating

Newton's second law vividly.

Scenario 3: Impulse and Momentum Transfer

A common situation involves applying a sudden force, or impulse, to the puck:

- Impulse (J):
Defined as the change in momentum,
$J = F \Delta t$.

- Effect on Momentum:
$\Delta p = J = m \Delta v$.
A sudden hit imparts a change in velocity:
$\Delta v = J / m$.

- Resulting Motion:
After the impulse, the puck moves with a new velocity, which remains constant unless acted upon by additional forces.
For example, a quick push of magnitude J results in:
$v = J / m$.

This scenario exemplifies the principle that impulses directly change the momentum of an object, a fundamental concept especially relevant in sports physics, such as hockey.

Scenario 4: External Forces Varying with Time or Position

In real-world applications, forces may not be constant. For example:

- A force that diminishes over time, perhaps due to fatigue or decreasing push strength.
- A force that varies with position, such as a magnetic or electric field gradient.

These cases require calculus-based approaches, integrating the force over time or space to determine the puck’s velocity and position as functions of time.

Energy Considerations in the System

Kinetic Energy and Work Done

On a frictionless surface, kinetic energy changes are solely due to work done by external forces:

- Work-Energy Theorem:
The work done by external forces equals the change in kinetic energy:
$W = \Delta KE$.

- Application:
When a force pushes the puck over a distance d, the work done is:
$W = F\ d \cos(\theta)$, where θ is the angle between force and displacement.

- Energy Conservation:
If the force is conservative (e.g., gravity), mechanical energy remains constant. If non-conservative forces are absent, the kinetic energy gained by the puck is directly attributable to the work done.

Potential Energy and External Fields

While the puck is on a flat, horizontal surface, potential energy related to gravity remains constant, as there is no vertical displacement. However, if external fields or inclines are introduced, potential energy considerations become significant, influencing the puck's motion and energy conversion.

Real-World Implications and Applications

Sports Physics and Engineering

Understanding the motion of a hockey puck on a frictionless surface isn't just academic; it has tangible applications:

- Designing Sports Equipment:
Engineers analyze puck behavior to optimize materials and surface conditions for better gameplay.

- Training and Performance Analysis:
Coaches use physics principles to refine techniques, such as slap shots or passes, by understanding how forces impart motion.

- Simulation and Virtual Reality:
Accurate physics models enable realistic virtual environments for training and entertainment.

Educational Value and Pedagogical Use

This simplified scenario serves as an excellent pedagogical tool:

- Demonstrates core physics concepts intuitively.
- Offers a controlled environment to test hypotheses about force, motion, and energy.
- Encourages hands-on experiments, such as pushing pucks with varying forces.

Advanced Topics and Extensions

Inclusion of Friction and Real-World Deviations

While the idealized model assumes no friction, real surfaces involve resistive forces. Incorporating friction introduces damping effects, leading to eventual stopping of the puck unless continuous external force is applied. The coefficient of kinetic friction (μ) would then influence acceleration:

$a = -\mu g$,

where g is acceleration due to gravity.

Rotational Dynamics and Spin

In actual hockey play, the puck often spins, affecting its stability and trajectory. Analyzing rotational motion involves moments of inertia, torque, and angular momentum, expanding the problem into a more complex but realistic domain.

Impact of External Fields and Obstacles

Additional external influences, such as magnetic fields or obstacles on the surface, create complex dynamics, including deflections, oscillations, or changes in velocity direction, enriching the study of physics in sports and engineering contexts.

Conclusion: The Significance of Fundamental Physics in Everyday Phenomena

The seemingly simple scenario of a hockey puck at rest on a frictionless surface encapsulates core principles of physics that extend far beyond the ice rink. From understanding how forces induce acceleration, how impulses alter momentum, to energy conservation, this model illustrates the elegance and predictive power of classical mechanics.

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