

A Toy Plane With A Mass Of 1.10 Kg Is Tied To A String And Made To Travel At A Speed Of 25.0 M/s In A

A Toy Plane With A Mass Of 1.10 Kg Is Tied To A String And Made To Travel At A Speed Of 25.0 M/s In A scenario, understanding the physics behind its motion can reveal insights into concepts such as tension, centripetal force, angular velocity, and energy conservation. This comprehensive guide delves into the principles governing such motion, offering an in-depth explanation suitable for students, educators, or enthusiasts interested in applying physics concepts to real-world or toy models. Whether you're analyzing the forces at play or calculating energy, this article covers all essential aspects to grasp the dynamics of a toy plane tied to a string executing circular motion.

Understanding the Basic Setup

To analyze the motion of the toy plane, it's crucial to understand the scenario:

- The toy plane has a mass of 1.10 kg.
- It is tied to a string, which constrains its motion.
- The plane travels at a constant speed of 25.0 m/s in a circular path.
- The motion occurs in a plane, and the string's tension provides the necessary centripetal force.

This configuration resembles a classic physics problem involving uniform circular motion, where an object moves at a constant speed along a circular path, maintained by inward force—here, the tension in the string.

Fundamental Concepts in Circular Motion

Before diving into calculations, it's important to understand key physics principles associated with circular motion:

Uniform Circular Motion

- Occurs when an object moves at a constant speed along a circular trajectory.
- The velocity vector continuously changes direction, implying acceleration.
- The acceleration points toward the center of the circle, called centripetal acceleration.

Centripetal Force

- The force required to keep an object moving in a circle.
- Calculated using the formula:

$$F_c = \frac{mv^2}{r}$$

where:

- m = mass of the object,
- v = tangential speed,
- r = radius of the circular path.

Tension in the String

- Acts as the centripetal force in this scenario.
- The magnitude of tension depends on the mass, speed, and radius of the circle.

Angular Velocity

- Represents how quickly the object completes a rotation.
- Calculated by:

$$\omega = \frac{v}{r}$$

where:

- ω = angular velocity,
- v = linear speed,
- r = radius of the circular path.

Calculating the Radius of the Motion

To analyze the forces, the radius of the circular path needs to be known or determined.

Scenario Assumption: Known Parameters

Suppose the toy plane is tied to the string and moving at 25.0 m/s, and the tension in the string is known or can be calculated based on other parameters.

Alternatively, if the problem provides the tension or other data, the radius can be found directly using the centripetal force formula:

$$r = \frac{mv^2}{F_c}$$

If the tension in the string (which equals the centripetal force) is known, radius can be calculated directly.

Calculations Involving Tension and Force

Suppose, for example, the tension in the string is measured or given as T . Then:

Determining the Tension

- If the setup involves additional forces, such as gravity or external forces, these need to be included.
- For a horizontal circular motion, gravitational effects are negligible, and tension provides the entire centripetal force.

1. Calculate the centripetal force:

$$F_c = \frac{mv^2}{r}$$

2. Set tension $T = F_c$ (assuming no other forces):

$$T = \frac{mv^2}{r}$$

Energy Considerations

Understanding the energy involved in the toy plane's motion offers insights into the conservation principles at play.

Kinetic Energy

- The kinetic energy (KE) of the plane is:

$$KE = \frac{1}{2}mv^2$$

- For the toy plane:

$$KE = \frac{1}{2} \times 1.10 \, \text{kg} \times (25.0 \, \text{m/s})^2 = 0.55 \times 625 = 343.75 \, \text{J}$$

Potential Energy

- Assuming motion occurs in a horizontal plane, potential energy changes are negligible.
- If the motion involves vertical components, gravitational potential energy must be considered.

Energy Conservation

- In ideal conditions (no friction or air resistance), kinetic energy remains constant.
- In real scenarios, energy losses due to air resistance may occur, affecting the tension and required force.

Applying the Concepts: Practical Example

Suppose you want to determine the tension in the string if the radius of the circular path is 5 meters.

Step-by-step Calculation

1. Identify known values:

- $m = 1.10 \, \text{kg}$
- $v = 25.0 \, \text{m/s}$
- $r = 5 \, \text{m}$

2. Calculate the centripetal force:

$$F_c = \frac{mv^2}{r} = \frac{1.10 \times (25.0)^2}{5} = \frac{1.10 \times 625}{5} = \frac{687.5}{5} = 137.5 \, \text{N}$$

3. The tension in the string equals the centripetal force:

$$(T = 137.5, \text{N})$$

This tension value indicates the force the string must withstand to keep the toy plane moving at this speed in the given radius.

Factors Affecting the Motion of the Toy Plane

Several factors influence the motion stability and force requirements:

1. Air Resistance

- Acts opposite to the plane's motion.
- Increases the tension needed for maintaining constant speed.

2. String Length and Flexibility

- Longer strings result in larger radii, affecting centripetal force.
- Flexible strings may introduce oscillations or instability.

3. External Forces and Acceleration

- External pushes or pulls can alter speed and path.
- Sudden changes in tension can cause the string to slack or break.

4. Friction and Surface Conditions

- If the setup involves a surface (like a table), friction reduces speed.
- For a free-flight scenario, air resistance dominates.

Safety and Design Considerations

When designing or experimenting with toy planes tied to strings, safety is paramount:

- Use sturdy, durable strings to withstand tension.
- Ensure the area is clear of bystanders.
- Avoid excessive speeds that may cause the string to snap.
- Regularly inspect the string and attachment points.

Conclusion: Physics in Action with Toy Planes

Analyzing a toy plane tied to a string moving at a consistent velocity exemplifies core physics principles in action. From calculating the tension required to sustain circular motion to understanding energy conservation, these concepts are fundamental in both education and practical applications. By grasping how mass, speed, radius, and forces interplay, enthusiasts and students gain a deeper appreciation for mechanics. Whether for classroom demonstrations, engineering prototypes, or fun experiments, understanding the physics behind a toy plane's motion enriches our comprehension of the natural world.

Remember: Always consider safety and realistic constraints when working with physical models or experiments involving motion and forces.

Frequently Asked Questions

What is the kinetic energy of the toy plane traveling at 25.0 m/s?

The kinetic energy (KE) is given by $KE = 0.5 \times \text{mass} \times \text{velocity}^2$. Substituting the values: $KE = 0.5 \times 1.10 \text{ kg} \times (25.0 \text{ m/s})^2 = 0.55 \times 625 = 343.75 \text{ Joules}$.

What is the tension in the string if the toy plane moves in a horizontal circle at 25.0 m/s with radius r ?

The tension (T) provides the centripetal force: $T = (\text{mass} \times \text{velocity}^2) / \text{radius}$. Without the radius, T cannot be precisely calculated, but the formula is $T = (1.10 \text{ kg} \times (25.0 \text{ m/s})^2) / r$.

How does increasing the speed to 30.0 m/s affect the tension in the string?

Increasing the speed increases the tension proportionally since $T = (\text{mass} \times \text{velocity}^2) / r$. Specifically, $T_{\text{new}} = (1.10 \text{ kg} \times 30.0^2) / r = (1.10 \text{ kg} \times 900) / r = 990 / r$, which is higher than at 25.0 m/s.

What is the angular velocity of the toy plane moving at 25.0 m/s in a circle of radius r?

Angular velocity $\omega = v / r$. Without the radius, ω cannot be numerically determined, but the formula is $\omega = 25.0 / r$ rad/s.

If the string breaks at high speed, what forces act on the toy plane afterward?

Once the string breaks, only gravitational force (if vertical) and air resistance act on the plane, and it will continue in a straight line due to inertia.

How does air resistance impact the motion of the toy plane at 25.0 m/s?

Air resistance opposes the motion, causing a gradual decrease in speed unless an external force is applied. Its effect becomes more significant at higher speeds.

What safety precautions should be taken when rotating a toy plane at 25.0 m/s?

Ensure the string and attachment are strong enough to withstand the tension, perform the experiment in a clear area away from people, and wear protective gear if necessary.

How would increasing the mass of the toy plane affect the tension in the string at the same speed?

Increasing the mass increases the tension proportionally, since $T = (\text{mass} \times \text{velocity}^2) / r$, making the string experience greater force at the same speed.

What are the practical applications of understanding the physics of a toy plane moving in a circle?

It helps in understanding real-world systems like centrifuges, amusement park rides, and the design of aircraft and spacecraft that involve circular motion and tension forces.

Additional Resources

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Introduction

In the realm of physics and engineering, seemingly simple experiments often reveal profound insights

into the fundamental principles governing motion and energy. Consider a toy plane with a mass of 1.10 kg, tethered to a string, and propelled to a speed of 25.0 meters per second in a controlled environment. Although it appears straightforward, this scenario encapsulates complex concepts such as kinetic energy, tension, centripetal force, and energy conservation. Understanding the dynamics at play not only provides an educational window into physics but also echoes the principles that underpin real-world applications—from aerospace engineering to amusement park rides.

This article delves into the detailed physics behind such a system, exploring the forces involved, energy considerations, and the implications of the toy plane's motion. We will dissect the problem step-by-step, elucidating the key principles with clarity and depth, making the subject accessible to readers with a foundational knowledge of physics but also engaging enough for enthusiasts seeking a deeper understanding.

Understanding the System: Basic Setup and Assumptions

Before exploring the physics, it's essential to define the system's parameters and assumptions:

- Mass of the toy plane (m): 1.10 kg
- Speed of the plane (v): 25.0 m/s
- Tether (string): Assumed to be massless and inextensible
- Motion type: Circular motion in a horizontal plane
- Environment: No significant air resistance or other external forces, unless specified
- Radius of circular path (r): To be determined or assumed based on context

The configuration suggests the toy plane is moving in a circular path, tethered by the string, which acts as a centripetal force provider. This setup is common in physics demonstrations illustrating circular motion, tension, and energy transfer.

Fundamental Physics Principles Involved

The analysis revolves around several core physics principles:

- Centripetal Force: The inward force necessary to keep an object moving in a circle.
- Tension in the String: The force exerted by the string, providing the centripetal force.
- Kinetic Energy: The energy the toy plane possesses due to its motion.
- Conservation of Energy: The relationship between potential energy, kinetic energy, and work done.
- Angular Velocity and Radius: Connection between linear speed and the geometry of motion.

Next, we will explore each in detail, contextualizing their roles within this specific scenario.

Centripetal Force and Tension in the String

When a toy plane moves in a circle at a constant speed, the string exerts a tension force, which acts as the centripetal force necessary to change the direction of the plane's velocity continuously. The magnitude of this tension (T) can be calculated using the centripetal force formula:

$$T = \frac{m v^2}{r}$$

Where:

- m is the mass of the object (1.10 kg),
- v is the tangential speed (25.0 m/s),
- r is the radius of the circular path (unknown, but can be derived or assumed).

Implications:

- As the speed increases, the tension in the string increases quadratically.
- The maximum tension the string can withstand determines the maximum feasible radius or speed without breaking.

To put this into perspective, suppose the string can withstand a maximum tension T_{max} . We can then determine the minimum radius for the given speed:

$$r_{\text{min}} = \frac{m v^2}{T_{\text{max}}}$$

Similarly, for a certain radius, we can find the maximum sustainable speed.

Kinetic Energy of the Toy Plane

The kinetic energy (KE) of the moving toy plane is a measure of the work needed to accelerate it from rest to its current speed:

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

Plugging in the known values:

$$KE = \frac{1}{2} \times 1.10 \, \text{kg} \times (25.0 \, \text{m/s})^2$$

$$KE = 0.55 \times 625$$

$$KE = 343.75 \, \text{J}$$

This energy represents the dynamic state of the toy plane and serves as a foundation for understanding energy transfer mechanisms—whether through initial propulsion or ongoing input.

Energy Considerations and Work-Energy Theorem

In an ideal, frictionless system, the kinetic energy of the toy plane remains constant once set in motion. However, in real-world scenarios, energy losses due to air resistance, string elasticity, and other factors occur. These losses require continuous work input to maintain the speed.

If the toy plane is to be accelerated to 25.0 m/s, the initial work done (ignoring losses) equals the kinetic energy calculated above. If an external motor or mechanism provides this energy, the

efficiency and power requirements depend on how quickly the speed is achieved.

Circular Motion Dynamics and Radius Determination

Suppose the goal is to understand the physical constraints better: what is the radius of the circular path at which the toy plane maintains a constant speed of 25.0 m/s? Rearranged from the centripetal force equation:

$$r = \frac{m v^2}{T}$$

If, for example, the maximum tension the string can withstand without breaking is known, say $T_{\max} = 10 \text{ N}$:

$$r = \frac{1.10 \text{ kg} \times (25.0 \text{ m/s})^2}{10 \text{ N}}$$

$$r = \frac{1.10 \times 625}{10}$$

$$r = \frac{687.5}{10}$$

$$r = 68.75 \text{ m}$$

This calculation demonstrates that, given the string's tension limit, the toy plane must travel in a circle with a radius of at least approximately 69 meters to sustain a speed of 25 m/s.

Implications for Design and Safety

Understanding the tension and energy involved informs several practical aspects:

- Material Selection: The string must withstand the tension at the desired speed. Stronger materials prevent snapping.
- Radius Constraints: Smaller radii at high speeds increase tension, risking failure.
- Speed Limits: There's a maximum speed permissible for a given radius and tension capacity, preventing accidents.
- Energy Input and Maintenance: Continuous energy input might be necessary to counteract damping effects such as air resistance, which dissipate energy as heat.

Real-World Applications and Analogies

While a toy plane tethered on a string is a simplified model, similar principles govern many engineering systems:

- Amusement Park Rides: Rotational rides operate at high speeds, requiring careful calculation of tension and energy to ensure safety.
- Centrifuges: Use circular motion principles to separate substances based on density.
- Aerospace Engineering: Launch vehicles and spacecraft utilize rotational and translational dynamics

that mirror these physics concepts.

- Physics Education: Demonstrations involving tethered objects effectively illustrate circular motion, tension, and energy conservation.

Conclusion

A toy plane tied to a string and traveling at 25.0 m/s encapsulates fundamental physics principles that extend beyond the classroom to real-world engineering and safety considerations. The tension in the string, the kinetic energy of the plane, and the radius of its circular path are interconnected through well-established equations governing circular motion.

Understanding these principles enables engineers and designers to optimize systems—whether in amusement parks, aerospace, or experimental physics—by balancing forces, energies, and material capacities. The simplicity of a toy plane belies the complexity and elegance of the physics it demonstrates, serving as both an educational tool and a stepping stone toward more advanced applications.

In essence, exploring such a system underscores the importance of physics in everyday life and technological innovation, illustrating how foundational concepts translate into practical, impactful solutions.

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