A 50-g Stone Is Tied To The End Of A String And Whirled In A Horizontal Circle Of Radius 2 Mat 20 M/s.

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This simple yet fascinating physics scenario provides an excellent opportunity to explore fundamental concepts such as centripetal force, tension in the string, and the dynamics of circular motion. Whether you're a student studying physics, a hobbyist interested in mechanics, or an educator preparing teaching materials, understanding the forces at play when a stone is whirled in a horizontal circle is essential. In this article, we delve into the physics behind this setup, analyze the forces involved, and discuss various related concepts to deepen your understanding of circular motion.

Understanding the Scenario: The Whirling Stone

Imagine a small 50-gram stone tied to the end of a string, which is being swung in a horizontal circle at a constant speed of 20 meters per second (m/s). The radius of this circular path is 2 meters. This setup is common in physics experiments and demonstrations that illustrate the principles of uniform circular motion.

Key Parameters:

- Mass of the stone (m): 50 grams (g)
- Radius of the circle (r): 2 meters (m)
- Speed of the stone (v): 20 meters per second (m/s)

Converting mass into SI units:
- 50 g = 0.05 kg

This conversion is crucial for calculating forces in standard SI units.

Calculating the Centripetal Force

The core principle behind the motion of the stone is the centripetal force, which is responsible for keeping the stone moving in a circle. This force acts directed toward the center of the circle, constantly changing the direction of the stone's velocity.

What is Centripetal Force?

Centripetal force is the inward force required to keep an object moving in a circular path at a constant speed. It is given by the formula:

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

Where:
- F_c = centripetal force (in newtons, N)
- m = mass of the object (kg)
- v = tangential velocity (m/s)
- r = radius of the circle (m)

Calculating the Force for the Given Parameters

Substituting the known values:

$$
F_c = \frac{0.05 \times (20)^2}{2} = \frac{0.05 \times 400}{2} = \frac{20}{2} = 10 \text{ N}
$$

Result: The tension in the string must be at least 10 N to maintain the circular motion at 20 m/s.

Analyzing the Tension in the String

The tension in the string provides the centripetal force necessary for the circular motion of the stone. Since the stone is whirling in a horizontal plane, the tension acts along the length of the string, directed toward the center of the circle.

Components of Tension:

- The tension force (T) acts along the string.
- In the case of horizontal circular motion, all of this tension acts horizontally, providing the centripetal force.
- If the motion involved vertical components, additional considerations such as gravity would come into play, but in this scenario, the motion is purely horizontal.

Tension Calculation:

As established, the tension needed to keep the stone moving at the specified speed is approximately 10 N.

Note: This tension must be sustained constantly to keep the stone moving in a circle, which involves maintaining the tension in the string throughout the motion.

Understanding the Forces: Tension and Centripetal Force

The tension in the string is directly related to the centripetal force needed for the motion.

Force Balance:

- The tension (T) supplies the inward force.
- The tension must equal the centripetal force:

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

Implications:

- If the tension exceeds this value, the stone accelerates inward, increasing the speed.
- If the tension is less than this, the stone will move outward, possibly breaking the string or causing the motion to stop.

Real-World Considerations:

- The maximum tension the string can withstand depends on its material properties.
- Ensuring the tension stays within safe limits prevents the string from snapping.

Calculating the Centripetal Acceleration

Centripetal acceleration is the acceleration experienced by the stone as it moves in a circle, directed toward the center.

Formula:

$$
a_c = \frac{v^2}{r}
$$

Calculation:

\[

$$
a_c = \frac{(20)^2}{2} = \frac{400}{2} = 200 \text{ m/s}^2
$$

Interpretation: The stone experiences a centripetal acceleration of 200 m/s^2, which is 200 times the acceleration due to gravity ($g \approx 9.8$ m/s^2). This highlights the significant forces involved in such motion.

Understanding the Role of String Length and Speed

The dynamics of circular motion depend heavily on the length of the string (radius) and the speed at which the stone is whirled.

Impact of Radius:
- Larger radius allows for higher speeds before breaking the string.
- The tension required for a given speed is directly proportional to the radius.

Impact of Speed:
- Increasing the speed increases the centripetal force exponentially, since $F_c \propto v^2$.

Practical Considerations:
- To safely whirl the stone at high speeds, the string must be strong enough to withstand the increased tension.
- The length of the string determines the radius and, thus, the necessary tension for a given speed.

Energy Considerations in Circular Motion

The motion of the stone involves kinetic energy, which depends on its mass and speed.

Kinetic Energy:

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

Calculating:

$$
KE = \frac{1}{2} \times 0.05 \times 400 = 0.025 \times 400 = 10 \text{ Joules}
$$

Insight: The kinetic energy of the stone is 10 Joules, which must be supplied to accelerate it to this speed. This energy comes from the person whirling the stone.

Energy Losses:

- Air resistance and friction can cause energy losses.
- Maintaining constant speed requires ongoing input of energy to counteract these losses.

Safety Precautions and Practical Applications

Whirling objects like stones or weights can be dangerous if not handled properly. It’s vital to consider safety measures and practical applications.

Safety Tips:

- Use a strong, durable string capable of withstanding high tension forces.
- Ensure a clear area free of obstacles and bystanders.
- Start with lower speeds to understand the limits of the setup.
- Always wear safety goggles to protect against potential string snaps or debris.

Practical Applications:
- Physics demonstrations to illustrate centripetal force.
- Amusement park rides involving circular motion.
- Training in sports like baseball or golf, where swinging involves rotational forces.
- Engineering applications involving rotating machinery.

Conclusion

Whirling a 50-g in stone in a horizontal circle of radius 2 meters at 20 m/s involves fundamental physics principles, primarily centripetal force and tension. The tension in the string must be approximately 10 N to keep the stone moving at this speed, producing a centripetal acceleration of 200 m/s^2. Understanding these forces helps in designing safe and effective circular motion systems, whether for educational demonstrations or practical engineering applications.

By analyzing the forces, energy, and motion involved, we gain a deeper appreciation of the elegant physics governing everyday phenomena. Whether in a classroom or a real-world setting, mastering the concepts of circular motion enables us to predict, control, and utilize rotational dynamics effectively.

Keywords for SEO:
- Circular motion physics
- Centripetal force calculation
- Tension in a rotating string
- Speed and radius in circular motion
- Energy in circular motion
- Centripetal acceleration
- Physics of whirling objects
- Safety in rotational experiments
- Practical applications of circular motion

Frequently Asked Questions

What is the tension in the string when a 50 g stone is whirled in a horizontal circle of radius 2 meters at 20 m/s?

The tension T can be calculated using the centripetal force formula: $T = (m v^2) / r$. Converting mass to kg: 50 g = 0.05 kg. So, $T = (0.05 20^2) / 2 = (0.05 400) / 2 = 20 / 2 = 10$ N. Therefore, the tension is 10 Newtons.

What is the centripetal acceleration of the stone in this scenario?

Centripetal acceleration $a = v^2 / r$. Substituting $v = 20$ m/s and $r = 2$ m, $a = (20)^2 / 2 = 400 / 2 = 200$ m/s^2.

How does the tension in the string change if the speed of the stone increases?

The tension increases proportionally to the square of the speed, since $T = (m v^2) / r$. Increasing the speed results in a higher tension in the string.

What is the role of the string in maintaining the circular motion of the stone?

The string provides the inward centripetal force necessary to keep the stone moving in a circle. It balances the outward inertial tendency and supplies the required force for circular motion.

If the speed of the stone is doubled, what happens to the tension in the string?

Since tension T is proportional to v^2, doubling the speed from 20 m/s to 40 m/s increases the tension by a factor of four. Original T = 10 N, new T = 4 10 = 40 N.

What is the significance of the radius in determining the tension in the string?

The radius determines the path of the circular motion; a larger radius reduces the required tension for a given speed, as tension is inversely proportional to the radius in the formula $T = (m v^2) / r$.

What are the possible causes if the string breaks during the whirling process?

The string may break if the tension exceeds its maximum tensile strength, which can happen due to high speeds, a too-weak or damaged string, or sudden acceleration increases.

How can the experiment be modified to increase the tension in the string without changing the speed?

Reducing the radius of the circle increases the tension since $T = (m v^2) / r$. Therefore, making the circle smaller while keeping the speed constant will increase the tension.

Additional Resources

A 50-g Stone Is Tied To The End Of A String And Whirled In A Horizontal Circle Of Radius 2 M At 20 M/s: An In-Depth Investigation

The dynamics of circular motion have long fascinated physicists, students, and engineers alike. The simple scenario of a stone tied to a string and whirled in a horizontal circle encapsulates fundamental principles of centripetal force, tension, and circular kinematics. In this comprehensive analysis, we delve into the physics underlying the motion of a 50-gram stone attached to a string of radius 2 meters, whirling at a speed of 20 meters per second. We explore the forces at play, calculate the tension in the string, examine implications for material strength, and discuss real-world applications and potential hazards.

Understanding the Scenario

Imagine a stone weighing 50 grams (0.05 kg) attached to a string with a length (radius of the circle) of 2 meters. It is swung in a horizontal circle at a constant tangential speed of 20 m/s. This setup, often used in physics classrooms, encapsulates key concepts of uniform circular motion.

Key parameters:
- Mass of the stone, $m = 0.05$ kg
- Radius of the circle, $r = 2$ m
- Tangential velocity, $v = 20$ m/s

The goal is to analyze the forces involved, especially the tension in the string, and understand the physical implications.

Fundamental Physics Principles

Uniform Circular Motion

When an object moves in a circle at constant speed, it experiences acceleration directed toward the center of the circle. This acceleration is known as centripetal acceleration, given by:

$$ a_c = \frac{v^2}{r} $$

The presence of acceleration necessitates an inward force, called the centripetal force, which is provided by the tension in the string:

$$ F_c = m a_c = m \frac{v^2}{r} $$

This force must be balanced by the tension T in the string.

Forces Acting on the Stone

- Tension in the string, T: Acts radially inward.
- Gravitational force, $F_g = mg$: Acts vertically downward.
- Since the motion is in a horizontal plane, the gravitational force acts perpendicular to the tension component that provides the centripetal force.

In an idealized scenario with a horizontal circle, the tension in the string must counteract the centripetal force, with gravity acting separately. If the string is inclined, the analysis becomes more complex, but for a purely horizontal circle, tension directly supplies the centripetal force.

Calculating the Tension in the String

Applying the centripetal force formula:

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

Plugging in the known values:

$$ T = 0.05\, \text{kg} \times \frac{(20\, \text{m/s})^2}{2\, \text{m}} $$

$$ T = 0.05\, \text{kg} \times \frac{400\, \text{m}^2/\text{s}^2}{2\, \text{m}} $$

$$ T = 0.05\, \text{kg} \times 200\, \text{m/s}^2 $$

$$ T = 10\, \text{N} $$

Result: The tension in the string required to maintain the circular motion at 20 m/s is 10 Newtons.

Physical Implications and Material Considerations

Stress on the String

The tension of 10 N exerts a force on the string, which must be within the material's tensile strength to prevent breaking. For common materials:

- Nylon or Polyester Strings: Tensile strengths typically range from 50 MPa to 300 MPa.
- Calculation of Tensile Stress:

$$ \text{Stress} = \frac{\text{Force}}{\text{Cross-sectional Area}} $$

Suppose the string has a diameter d = 1 mm (0.001 m):

$$ \text{Area} = \pi \left(\frac{d}{2} \right)^2 = \pi \times (0.0005)^2 \approx 7.85 \times 10^{-7} \text{ m}^2 $$

Tensile stress:

$$ \sigma = \frac{10\, \text{N}}{7.85 \times 10^{-7}\, \text{m}^2} \approx 1.27 \times 10^{7}\, \text{Pa} = 12.7\, \text{MPa} $$

This stress is well below the tensile strength of typical nylon or polyester, indicating the string can withstand the tension safely, assuming no flaws.

Safety Margins and Practical Considerations

- Material Fatigue: Repeated whirling can cause wear.
- Dynamic Load Variations: Sudden jerks or variations in speed increase tension.
- Environmental Factors: Moisture, UV exposure, and temperature can degrade material strength.

Proper selection of string material and diameter is critical for safety, especially at high speeds.

Energy and Kinetic Considerations

Kinetic Energy of the Stone

The kinetic energy (KE) of the stone:

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

$$ KE = \frac{1}{2} \times 0.05\, \text{kg} \times (20\, \text{m/s})^2 = 0.025\, \text{kg} \times 400\, \text{m}^2/\text{s}^2 = 10\, \text{J} $$

This energy indicates the amount of work needed to accelerate the stone to this speed, and how much energy would be released if the string breaks.

Implications for Safety and Design

High kinetic energy means that failure of the string could result in the stone becoming a dangerous projectile, potentially causing injury or damage.

Analyzing the Centripetal Force at Different Speeds and Radii

The tension required varies with speed and radius:

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

- Increasing speed exponentially increases tension.
- Decreasing radius, similarly, increases tension.

For example:

Speed (m/s)	Tension (N) at r=2 m
10	2.5
15	5.625
20	10
25	15.625

Similarly, halving the radius would double the tension at the same speed.

Real-World Applications and Broader Significance

Educational Demonstrations

This scenario serves as a classic physics demonstration, illustrating the relationship between velocity, radius, and force. It helps students visualize how tension varies with speed and how centripetal force operates.

Engineering and Safety Design

Understanding these principles is essential in designing:

- Amusement park rides involving circular motion.
- Rotating machinery components.
- Satellite and space station rotational habitats.

Material selection, safety margins, and force calculations are critical to prevent catastrophic failures.

Sports and Recreation

- Design of tethered sports equipment like tetherball or discus throwers.
- Ensuring athlete safety through understanding forces involved.

Potential Hazards and Precautions

- High-speed rotation increases the risk of string failure.
- Proper anchoring and material checks are essential.
- Use of safety shields and protective gear is recommended during experiments.
- Regular maintenance and inspection of equipment.

Conclusion

The analysis of a 50-g stone tied to a string and whirled in a horizontal circle at 20 m/s reveals a tension of approximately 10 Newtons required to sustain such motion. This investigation underscores the importance of material strength, safety considerations, and the fundamental physics governing circular motion. Whether in educational settings, engineering applications, or recreational activities, understanding these principles ensures safe and effective utilization of rotational systems. As speeds increase or radii decrease, the forces involved escalate, demanding careful engineering considerations to prevent failures and ensure safety.

By thoroughly examining the forces, energies, and materials involved, this case study exemplifies core physics concepts and their practical implications, reinforcing the importance of precise calculations and safety awareness in dynamic systems involving circular motion.

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