A Stone Is Tied To A String And Whirled In A Vertical Circle At A Radius. Which Of The Following Cannot

A Stone Is Tied To A String And Whirled In A Vertical Circle At A Radius. Which Of The Following Cannot be achieved or explained through the principles of physics? This question often arises in physics classes and competitive exams to evaluate understanding of circular motion, tension, gravity, and energy conservation. In this comprehensive article, we will explore the physics behind vertical circular motion, analyze what can and cannot happen in such a setup, and clarify common misconceptions. By the end of this article, you'll have a clear understanding of the factors that influence the motion of a stone tied to a string and whirled in a vertical circle.

Understanding Vertical Circular Motion

Basic Concepts of Circular Motion

Circular motion occurs when an object moves along a circular path. It can be uniform, where the speed remains constant, or non-uniform, where the speed varies. The key aspects of circular motion include:

- Radius (r): The fixed distance from the center of the circle to the moving object.
- Angular velocity (ω): The rate at which the object moves around the circle.
- Tangential velocity (v): The linear speed along the circular path, related to angular velocity by $v = r\omega$.
- Centripetal force: The inward force that keeps the object moving in a circle, directed towards the center.

In the case of a stone tied to a string and whirled in a vertical circle, the motion is non-uniform because the velocity varies at different points of the circle.

Vertical Circular Motion Specifics

In vertical circular motion, gravity plays a significant role. The tension in the string must balance both the centripetal force and the component of gravitational force acting along the radius. The motion has distinct points:

- Top of the circle: The stone is at the highest point.
- Bottom of the circle: The stone is at the lowest point.
- Intermediate points: Positions between the top and bottom.

The key challenge is understanding how tension and gravitational forces vary at these points and how they influence the motion.

Forces Acting on the Stone in Vertical Circular Motion

At the Bottom of the Circle

- Gravity: Acts downward, towards the center of Earth.
- Tension in the string: Acts upward, towards the center of the circle.
- Centripetal force requirement: The tension must be sufficient to provide the necessary inward force to keep the stone moving in a circle.

The net inward force (centripetal force) at the bottom is:

$$ T_{bottom} - mg = \frac{mv^2_{bottom}}{r} $$

where:

- $ T_{bottom} $ = tension at the bottom,
- $ m $ = mass of the stone,
- $ g $ = acceleration due to gravity,
- $ v_{bottom} $ = velocity at the bottom.

At the Top of the Circle

- Gravity: Acts downward.
- Tension: Also acts downward (towards the center at the top).
- Centripetal force: Provided by tension plus gravity.

The force balance at the top:

$$ T_{top} + mg = \frac{mv^2_{top}}{r} $$

where:

- $ T_{top} $ = tension at the top,
- $ v_{top} $ = velocity at the top.

It's important to note that tension can be zero at the top if the velocity is just sufficient to keep the stone moving in a circle.

Analysis of What Cannot Occur in Vertical Circular Motion

Understanding the constraints of physical forces allows us to identify what situations are impossible or physically inconsistent.

1. The Tension Becomes Negative

- Explanation: Tension cannot be negative because it is a pulling force; it cannot push.
- Implication: The tension in the string at any point must be zero or positive.
- Why it Cannot: If calculations yield a negative tension, it indicates that the stone cannot maintain the circular motion at that point with the given parameters (mass, radius, initial speed). The stone would then lose contact with the string, breaking the circular path.

2. The Velocity at the Top Is Less Than a Critical Value

- Critical velocity at the top: The minimum velocity necessary to keep the string taut, which occurs when tension is zero.
- Calculation:

$$v_{top\,min} = \sqrt{g r}$$

- Why it Cannot: If the velocity at the top is less than this, tension becomes negative or zero, meaning the string would slack, and the circular motion cannot be sustained.

3. The Tension at the Top Is Zero but the Speed Is Insufficient

- Scenario: For the string to just remain taut at the top, the velocity must be at least $\sqrt{g r}$.
- Impossible situation: If the stone's speed at the top is less than this, it will lose contact with the string, and the motion will no longer be circular.

4. The Stone Moves in a Path That's Not Circular

- Explanation: The initial conditions and forces must be such that the motion remains circular.
- Impossible if: External forces are applied that significantly alter the trajectory or if the tension cannot sustain the necessary centripetal force.

5. The Tension Exceeds Physical Limits

- Scenario: For extremely high speeds, tension can become very large.
- Physical constraint: The string must withstand the tension without breaking.
- Impossible situations: If calculations suggest tension exceeds the string's maximum tensile strength, then such a motion cannot be physically realized.

Conditions for Successful Vertical Circular Motion

To understand what can occur, it's essential to recognize the conditions under which the stone maintains circular motion:

Initial Speed Requirements

- The initial velocity at the bottom must be sufficient to ensure the velocity at the top is at least $\sqrt{g r}$.
- This is derived from energy conservation principles.

Energy Conservation

The total mechanical energy at the bottom and top (ignoring air resistance) can be equated:

$$\frac{1}{2} m v_{bottom}^2 = \frac{1}{2} m v_{top}^2 + 2 m g r$$

Rearranged to find the minimum initial velocity at the bottom:

$$v_{bottom,min} = \sqrt{5 g r}$$

This minimum speed ensures the stone reaches the top with exactly $\sqrt{g r}$ velocity, maintaining tension.

Maximum Speed Constraints

- The tension at the bottom increases with the square of the velocity.
- Excessively high speeds can cause the string to break unless it is designed to withstand such tension.

Real-World Applications and Experiments

Understanding the physics of vertical circular motion is crucial in various fields, including engineering, amusement park rides, and physics experiments.

Amusement Park Rides

- Many rides involve cars or carts moving in vertical circles.
- Engineers must calculate the minimum speeds to ensure safety and comfort.
- Tension forces are managed by designing robust support structures.

Physics Demonstrations

- Laboratory experiments often involve whirling a stone or a mass on a string.
- They visually demonstrate principles like energy conservation, tension, and the effects of gravity.

Sports and Engineering

- Athletes perform circular motions (e.g., figure skating, gymnastics).
- Engineers design rotating machinery considering forces involved in circular motion.

Summary and Key Takeaways

- The motion of a stone tied to a string and whirled in a vertical circle involves balancing gravitational forces, tension, and centripetal force.
- Tension is always non-negative; negative tension (pushing force) is physically impossible.
- The minimum velocity at the top of the circle is $\sqrt{g r}$ to keep tension positive; below this, the stone

cannot sustain circular motion.
- The initial speed must be sufficiently high to reach the top with the required velocity.
- Excessively high speeds can cause the tension to exceed the string's strength, leading to breakage.
- External factors such as air resistance and string elasticity also influence real-world motion but are often neglected in ideal physics problems.

Final Thoughts

Understanding the constraints and forces in vertical circular motion clarifies what can and cannot happen during such motion. Recognizing that tension cannot be negative and that the initial conditions are critical helps in solving physics problems accurately. Whether designing amusement park rides or conducting physics experiments, these principles are fundamental to ensuring safe and realistic motion.

If you encounter a problem such as, "A stone is tied to a string and whirled in a vertical circle at a radius. Which of the following cannot happen?" remember to analyze the forces involved, apply energy conservation, and check the feasibility of the tension and velocity values. This approach provides clarity and ensures sound reasoning grounded in physics principles.

References:

- Fundamentals of Physics by David Halliday, Robert Resnick, and Jearl Walker
- Physics for Scientists and Engineers by Raymond A. Serway and John W. Jewett
- Online physics resources and educational websites like Khan Academy and HyperPhysics

Frequently Asked Questions

What is the primary factor determining the tension in the string when whirling a stone in a vertical circle?

The tension depends on the speed of the stone, the radius of the circle, and the position of the stone in the vertical path, especially balancing the gravitational force.

Why can't the tension in the string be zero at the top of the vertical circle while whirling a stone?

Because at the top, the tension must at least counteract the weight of the stone to keep it moving in a circular path; zero tension would mean the stone is just about to lose contact, which is not sustainable during continuous whirling.

Which factors influence the maximum speed at which a stone can be whirled in a vertical circle without the string slackening?

The maximum speed depends on the length of the string, the mass of the stone, and the gravitational acceleration, as these determine the minimum tension needed at the top of the circle.

Can the stone be whirled in a vertical circle at any radius? Why or why not?

No, because if the radius is too small or the speed too low, the tension at the top may become zero or negative, causing the stone to lose contact with the string.

Which of the following cannot be true when whirling a stone in a vertical circle: the tension is zero at the top, the tension is maximum at the bottom, or the string breaks at any point?

The tension being zero at the top cannot be sustained during continuous whirling because it implies the stone is on the verge of losing contact, which is physically impossible during steady motion.

How does increasing the speed of the stone affect the tension in the string at different points in the vertical circle?

Increasing the speed increases the tension at all points, especially at the bottom where the tension is maximum, and can prevent the tension from dropping to zero at the top.

What is the significance of the minimum speed required at the top of the circle?

It ensures that the tension in the string remains zero or positive, preventing the stone from losing contact with the string during the whirling motion.

Which scenario demonstrates a situation that cannot occur when whirling a stone in a vertical circle?

A situation where the tension in the string is negative at the top of the circle, indicating the stone would be pulling away from the string, which cannot happen during steady motion.

Why is it impossible to whirl a stone in a vertical circle with a radius larger than a certain limit at a given speed?

Because beyond a certain radius, the required speed to maintain tension becomes unattainably high, making it impossible to keep the tension positive at all points in the circle.

Additional Resources

A stone is tied to a string and whirled in a vertical circle at a radius—this classic physics scenario offers a rich ground for exploring the principles of circular motion, energy conservation, and the forces at play. Whether you're a student preparing for exams, an educator designing demonstrations, or simply a physics enthusiast, understanding the intricacies of this problem deepens your grasp of fundamental mechanics. In this guide, we will dissect the problem thoroughly, analyze what cannot occur in such a system, and clarify common misconceptions.

Understanding the Scenario

Imagine a stone attached to a string of fixed length (radius) being swung in a vertical circle. The motion involves several physical concepts:

- Centripetal Force: The inward force required to keep the stone moving in a circle.
- Tension in the String: The force exerted by the string on the stone, which varies throughout the motion.
- Gravitational Force: The weight of the stone acting downward.
- Energy Conservation: The interplay between potential and kinetic energy as the stone moves along the vertical path.

The key to analyzing such a problem lies in understanding how these forces balance and how the energy transforms as the stone moves through different points in its circular path.

Breaking Down the Motion in a Vertical Circle

Positions in the Vertical Circle

The motion can be segmented into key points:

- Top of the circle: The stone is at the highest point.
- Bottom of the circle: The stone is at the lowest point.
- Intermediate points: Positions between the top and bottom.

Important Variables

- Radius (r): Distance from the center of the circle to the stone.
- Mass of the stone (m): Influences the forces involved.
- Speed at various points (v): Varies depending on position and energy.

Forces Acting on the Stone

At any point during the motion, the forces are:

- Tension (T): Acts along the string, directed toward the center.
- Gravity (mg): Acts downward, constant throughout the motion.

The net inward force (centripetal force) is provided by the sum of tension and component of gravity, depending on the position.

Energy Considerations

Assuming no air resistance or other dissipative forces, mechanical energy remains conserved:

$$\text{Potential Energy (PE)} + \text{Kinetic Energy (KE)} = \text{Constant}$$

Choosing the lowest point as zero potential energy, the potential energy at height h is:

$$PE = mgh$$

and kinetic energy:

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

This conservation allows us to determine the velocity at different points:

$$\frac{1}{2}mv^2 + mgh = \text{constant}$$

What Can Actually Occur?

Given the physical principles, certain behaviors are possible, while others are impossible due to constraints such as tension becoming negative (which cannot happen physically) or the stone losing contact with the string.

Common Valid Scenarios

- The tension is greatest at the bottom of the circle.
- The tension can become zero at the top if the stone just maintains contact.
- The speed at the top is less than at the bottom, as energy converts between potential and kinetic.
- The stone can complete the circle if initial conditions (like initial speed) are sufficient.

Which of the Following Cannot Occur?

In typical multiple-choice questions, options are presented describing different behaviors or states of the stone during its motion. The question often asks: "Which of the following cannot occur?"

Examples of options that cannot occur include:

- The tension in the string is negative at any point.
- The stone has zero velocity at any point in the motion (unless it is losing contact).
- The stone moves in a circle with radius larger than the initial radius.
- The tension is greater than the weight of the stone at the top of the circle.
- The stone is at rest at the top of the circle but not in contact with the string.

Let's analyze these scenarios:

In-Depth Analysis of Impossible Situations

1. Negative Tension in the String

Why it cannot occur:
Tension is a contact force exerted by the string on the stone. It cannot be negative because the string cannot pull in the opposite direction—it's designed to exert a pulling force, not a pushing force. When the tension would need to be negative (for example, at the top of the circle if the required inward force exceeds the available inward component), the stone would lose contact with the string. Essentially, negative tension signifies detachment, which is physically impossible in the context of the string retaining contact.

Conclusion:
Negative tension cannot occur if the string remains taut and the stone stays in contact.

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2. Zero Velocity at Any Point (Without Detachment)

Why it cannot occur:
In a frictionless system, the stone's velocity drops as it ascends to higher points due to energy conservation. At the very top, the velocity may be minimal but still positive if the stone continues to stay in contact. If the stone reaches zero velocity exactly at a point in the motion, it must momentarily be at rest. However, unless it is at the top and just about to lose contact, the stone cannot be exactly at rest in mid-motion without detachment.

Special note:

If the stone does reach zero velocity at the top, then tension must be zero, meaning it just maintains contact before losing it. So, zero velocity at the top is possible, but anywhere else in the path, not.

Conclusion:
Zero velocity at a point in the middle of the circle without detachment is impossible.

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3. Moving in a Circle with a Radius Larger Than the Initial Radius

Why it cannot occur:
The radius of the circle is fixed by the length of the string. The stone cannot suddenly move in a circle of larger radius unless the string length changes, which contradicts the problem statement.

Conclusion:
The radius of the circle cannot change during the motion.

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4. Tension Greater Than the Weight at the Top

Why it cannot occur:
At the top, the tension in the string plus the component of gravity must provide the necessary centripetal force:

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

Since gravity (mg) acts downward, the tension T can be greater than, equal to, or less than mg depending on the speed. But tension cannot be less than zero, and physically, it can be greater than mg if the speed is sufficiently high, so there's no problem with $T > mg$ at the top.

However, if the tension was less than zero, that's impossible, but $T > mg$ is plausible.

Conclusion:
Tension can be greater, equal, or less than mg; the impossible scenario would be negative tension.

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5. The Stone Is at Rest at the Top but Not in Contact

Why it cannot occur:
If the stone is at rest at the top (zero velocity), unless it is about to detach, the tension would have to be zero for the stone to stay in contact without moving. But if the stone is "at rest" (zero velocity) at the top and still in contact, then the forces are balanced:

$$ T + mg = 0 $$

which implies tension is negative, impossible for a tension force. Therefore, the stone cannot be at rest at the top while still in contact unless the tension is zero, indicating just about to lose contact.

Conclusion:
The stone cannot be at rest at the top while still maintaining contact unless it is about to lose contact.

Summarizing the Key Point: What Cannot Happen?

The most definitive impossible scenario in the context of a stone tied to a string whirled in a vertical circle is:

The tension in the string becoming negative while the stone remains in contact.

This is physically impossible because the string cannot exert a pushing force. When the tension approaches zero, the stone is on the verge of losing contact—if it drops below zero, contact is lost, and the motion becomes disconnected from circular path constraints.

Practical Implications and Real-World Examples

- Amusement park rides: Engineers design swings and rides ensuring tension remains positive throughout the motion.
- Physics experiments: Demonstrate that at the top of the loop, the minimal velocity required keeps tension non-negative.
- Sports: Athletes swinging a ball on a string must maintain sufficient speed to avoid detachment at the top.

Final Thoughts

Understanding which behaviors are physically possible or impossible in a vertical circular motion scenario hinges on grasping the interplay between forces, energy conservation, and the constraints of the system. Recognizing that negative tension cannot occur if the string remains taut is crucial, as is understanding the conditions under which the stone can or cannot be at rest mid-motion.

This detailed examination not only clarifies the specific question of what cannot happen but also deepens your overall comprehension of circular motion physics, aiding in analysis, problem-solving, and practical applications.

In summary:
- The tension in the string cannot be negative while the string is taut.
- The stone cannot be at rest at any point in the circle without losing contact unless it is at the top with zero tension.
- The radius of the circle is fixed by the string length and cannot change during the motion.
- The stone cannot move in a circle of larger

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