A Horizontal Meter Stick Supported At The 50-cm Mark Has A Mass Of 0.5kg Hanging From It At The 20-cm

Introduction

A horizontal meter stick supported at the 50-cm mark has a mass of 0.5 kg hanging from it at the 20-cm mark. This seemingly simple setup offers a rich context for exploring fundamental concepts in physics, particularly in statics and rotational equilibrium. Analyzing such a system helps us understand how forces and torques interact to maintain equilibrium, how to determine the reactions at the support, and how the placement of masses affects the overall stability of the system. In this article, we delve deeply into the mechanics governing this setup, dissecting each element to develop a comprehensive understanding of the principles involved.

Understanding the Setup

Components of the System

The system consists of three main components:

- **The meter stick:** A uniform rod of length 100 cm (1 meter), mass m_{stick}, assumed to be distributed evenly along its length.
- **The support:** A fixed support located at the 50-cm mark, which provides a reaction force to keep the stick horizontal.
- **The hanging mass:** A mass of 0.5 kg attached at the 20-cm mark, hanging from the meter stick.

Assumptions and Simplifications

To analyze the system effectively, certain assumptions are made:

1. The meter stick is rigid and massless or its mass is negligible unless specified.
2. Friction at the support is negligible; the support only provides vertical reaction force.
3. The gravitational acceleration g is constant at 9.8 m/s^2.
4. All forces are statically balanced; the system is in equilibrium.

Analyzing the Forces and Torques

Forces Acting on the System

The forces involved include:

- **Gravity on the hanging mass:** $F_{mass} = m_{mass} \times g = 0.5\, \text{kg} \times 9.8\, \text{m/s}^2 = 4.9\, \text{N}$.
- **Gravity on the meter stick:** Since the stick is assumed uniform, its weight acts at its center of mass, located at the 50-cm mark.
- **Reaction force from support:** R, acting vertically upward at the 50-cm mark.

Torque Calculations

To analyze equilibrium, we apply the principle of moments (torques). The sum of torques about any point must be zero for the system to be in equilibrium.

Choosing the support point at the 50-cm mark simplifies calculations because the reaction force acts there, producing no torque about that point.

- Torque due to the hanging mass:

The hanging mass is at the 20-cm mark, which is 30 cm (or 0.3 m) to the left of the support at 50-cm.

$$
\tau_{mass} = F_{mass} \times \text{distance} = 4.9\, \text{N} \times 0.3\, \text{m} = 1.47\, \text{Nm}
$$

Since this force acts downward and is located to the left of the support, it produces a clockwise torque.

- Torque due to the meter stick's weight:

The weight acts at the 50-cm mark, directly above the support, so its torque about the support is zero.

$$
\tau_{stick} = 0
$$

- Reaction force:

The reaction force R acts upward at the support point; thus, it produces no torque about the support.

Applying the equilibrium condition:

$$
\sum \tau = 0
$$

$$
\Rightarrow \text{Counter-clockwise torques} = \text{Clockwise torques}
$$

Since the reaction force and the weight of the stick produce no torque about the support, the only torque to balance is from the hanging mass:

$$
R \text{ and the stick's weight} \text{ produce no net torque about the support}
$$

but the downward force from the hanging mass tends to rotate the stick clockwise. Therefore, the support must exert a reaction force to balance this torque.

Total vertical force balance:

$$
R + W_{stick} = W_{mass}
$$

where W_{stick} is the weight of the meter stick:

$$
W_{stick} = m_{stick} \times g
$$

If the stick's mass is known or assumed negligible, the reaction force can be directly calculated.

Calculating the Reaction Force at the Support

Considering the Mass of the Meter Stick

If the meter stick's mass is known, the calculation of the reaction force becomes straightforward.

- Assuming the meter stick has a mass m_{stick}:

$$
W_{stick} = m_{stick} \times g
$$

- Total downward force:

$$
F_{total} = W_{stick} + W_{mass}
$$

- Applying static equilibrium:

Since the system is in equilibrium, the upward reaction force R must balance the total downward forces:

$$
R = W_{stick} + W_{mass}
$$

Example:

Suppose the meter stick has a mass of 0.2 kg:

$$
W_{stick} = 0.2\, \text{kg} \times 9.8\, \text{m/s}^2 = 1.96\, \text{N}
$$

Total weight:

$$
W_{total} = 4.9\, \text{N} + 1.96\, \text{N} = 6.86\, \text{N}
$$

Since the weight of the stick acts at its center (50-cm mark), and the hanging mass is at 20-cm, the torque balance about the support becomes:

$$
\text{Clockwise torque} = 4.9\, \text{N} \times 0.3\, \text{m} = 1.47\, \text{Nm}
$$

The weight of the stick acts at the 50-cm mark directly above the support, producing no torque.

The reaction force R acts upward, and since it is at the support, it produces no torque about the support point.

Thus, the vertical equilibrium condition:

$$
R = W_{stick} + W_{mass} = 6.86\, \text{N}
$$

And the torque balance:

$$
\text{Sum of torques} = 0 \Rightarrow 1.47\, \text{Nm} \text{ (clockwise) }= R \times 0\, \text{m} + \text{other torques}
$$

But since the reaction acts at the support, it produces no torque about that point. The only torque to counteract is from the hanging mass, which is balanced by the vertical force components in the system.

Impact of Mass Placement and Support Location

Effects on System Equilibrium

The position of the hanging mass relative to the support affects the magnitude of the torque and, consequently, the reaction force required at the support.

- Closer to the support: The torque exerted by the hanging mass decreases as its distance from the support shrinks, reducing the reaction force needed.

- Farther from the support: The torque increases linearly with distance, necessitating a higher reaction force to maintain equilibrium.

Similarly, the position of the support impacts the system's stability:

- Support at the center (50-cm mark): Symmetrical and typically most stable.

- Support closer to one end: May introduce imbalance, requiring additional considerations such as structural stability or additional supports.

Calculating Reactions for Different Support Positions

Suppose the support is moved to a different point x along the meter stick. The torque balance about this new support involves considering the positions of the hanging mass and the stick's weight.

- Torque due to the hanging mass:

$$
\tau_{mass} = m_{mass} \times g \times (x_{mass} - x)
$$

- Torque due to the stick's weight:

$$
W_{stick} \times (50\, \text{cm} - x)
$$

By summing torques and forces, one can determine the reaction force at the new support location, ensuring the system remains in equilibrium.

Practical Applications and Significance

Educational Value

This setup is frequently used in physics labs to demonstrate principles of static equilibrium, torque, and center of mass. It helps students visualize how forces balance and how the placement of weights affects stability.

Engineering and Structural Design

Understanding such systems is crucial in designing beams, bridges, and other structures where load distribution and support placement are vital for safety and efficiency.

Real-World

Frequently Asked Questions

What is the purpose of supporting a horizontal meter stick at the 50-cm mark?

Supporting the meter stick at the 50-cm mark provides a balanced pivot point, allowing the stick to remain horizontal while measuring or analyzing forces and torques acting on it.

How do you calculate the torque caused by the hanging mass on the meter stick?

The torque is calculated by multiplying the force due to the mass (weight) by the perpendicular distance from the pivot point. For a mass m hanging at a distance d from the pivot, torque = m g d, where g is acceleration due to gravity.

What is the weight of the 0.5kg mass hanging from the meter stick?

The weight is calculated as mass times gravity: 0.5 kg 9.8 m/s² = 4.9 N.

How can we determine the additional force required to keep the meter stick in equilibrium?

The additional force depends on balancing the torque caused by the hanging mass. By calculating the torque and ensuring the sum of clockwise and counterclockwise torques equals zero, you can find the required support force or reactions at the pivot.

If the meter stick has a mass of 0.5 kg, what is its weight, and how does it affect the forces acting on the support?

The weight of the meter stick is 0.5 kg 9.8 m/s² = 4.9 N. This weight acts at the center of mass (midpoint), creating additional torque that must be considered along with the hanging mass when analyzing forces at the support.

Why is it important to support the meter stick at the 50-cm mark when analyzing forces or moments?

Supporting at the 50-cm mark, near the center, minimizes the net torque and simplifies analysis by providing a stable pivot point, making it easier to calculate moments and forces acting on the system.

Additional Resources

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Introduction

In the realm of physics and mechanics, understanding how forces and torques operate on simple systems is fundamental. The scenario of a horizontal meter stick supported at a specific point with a mass hanging from it provides a rich context to explore principles like equilibrium, torque, and center of mass. This particular case — a meter stick supported at the 50-cm mark with a 0.5 kg mass hanging at the 20-cm mark — serves as an ideal example to analyze the distribution of forces, the conditions for equilibrium, and the implications for structural stability.

This article aims to dissect this setup comprehensively, delving into the physics principles involved, performing precise calculations, and analyzing the broader implications for understanding static equilibrium. Such an exploration offers valuable insights not only for students and educators but also for engineers and practitioners working with structural systems.

The Basic Setup: Understanding the System Components

The Meter Stick

A typical meter stick is a rigid, uniform rod, usually made of wood or plastic, with a length of exactly 1 meter (100 centimeters). Its mass distribution is generally uniform, implying that its center of mass coincides with its geometric center — the 50-cm mark. For simplicity in calculations, the meter stick's mass and weight are considered to be evenly distributed along its length.

Key properties:

- Length: 100 cm (1 meter)
- Mass: Typically around 0.5 kg (as assumed in the scenario)
- Center of mass: Located at the 50-cm mark

The Support Point

The meter stick is supported at the 50-cm mark. This point acts as a fulcrum, providing a reaction force that counteracts the weights acting on the system. The support's role is crucial because it determines the distribution of torques and the overall stability of the system.

The Hanging Mass

A mass of 0.5 kg is suspended from the meter stick at the 20-cm mark. This creates a point load, exerting a downward force due to gravity, which influences the torque about the support point. The position at 20 cm indicates that the mass is located 30 cm to the left of the support point (since 50 cm is the support, and the mass is at 20 cm).

Analyzing the Forces: Equilibrium Conditions

The Principle of Static Equilibrium

For the system to be in static equilibrium, two conditions must be satisfied:

1. Sum of vertical forces must be zero:

$$
\sum F_y = 0
$$

2. Sum of torques about any point must be zero:

$$
\sum \tau = 0
$$

Applying these principles allows us to determine the reaction forces at the support and understand how the system maintains balance.

Calculating the Forces and Torques

Step 1: Identify the forces

- Weight of the meter stick (W_s):

$$
W_s = m_s \times g = 0.5\, \text{kg} \times 9.8\, \text{m/s}^2 = 4.9\, \text{N}
$$

- Weight of the hanging mass (W_m):

$$
W_m = m_m \times g = 0.5\, \text{kg} \times 9.8\, \text{m/s}^2 = 4.9\, \text{N}
$$

- Reaction force at the support (R):

This is the vertical force exerted by the support at the 50-cm mark. It will have an upward magnitude balancing the downward forces, assuming no other external forces.

Step 2: Choosing the pivot point

To analyze torques, the typical approach is to select the support point (at 50 cm) as the pivot. This simplifies calculations because the reaction force acts at the pivot point, producing zero torque about that point, allowing us to focus solely on the torques caused by the weights.

Step 3: Determine torques about the support point

- Torque due to the meter stick's weight (W_s):

Since the center of mass of the meter stick is at 50 cm, and the support is also at 50 cm, the weight acts directly at the pivot point, producing zero torque.

- Torque due to the hanging mass (W_m):

The mass hangs at 20 cm, which is 30 cm (or 0.3 m) to the left of the support.

$$
\tau_{m} = W_m \times d = 4.9\, \text{N} \times 0.3\, \text{m} = 1.47\, \text{Nm}
$$

This torque acts clockwise, tending to rotate the stick downward on the left side.

- Reaction force (R):

The reaction force at the support acts vertically upward at the pivot point, producing no torque about that point.

Step 4: Vertical force balance

$$
R = W_s + W_m = 4.9\, \text{N} + 4.9\, \text{N} = 9.8\, \text{N}
$$

However, this assumes the system is in equilibrium without any additional torques. Let's verify the torque balance.

Confirming Equilibrium: Torque Balance

Since the only torque about the pivot point is due to the hanging mass, and there is no torque contribution from the meter stick's weight (as it acts at the pivot), the system is in equilibrium if the reaction force's torque balances the torque from the hanging mass.

In static equilibrium:

$$
\text{Clockwise torques} = \text{Counterclockwise torques}
$$

In this case, because the reaction force acts at the pivot, it produces no torque, so the net torque is solely from the hanging mass.

Given that, the system is balanced vertically with the reaction force at approximately 9.8 N, matching the total weight of the system.

Broader Implications and Advanced Analysis

While the above calculations provide a straightforward understanding, real-world scenarios involve additional considerations, such as the distribution of the meter stick's mass, potential bending stresses, and stability under dynamic conditions.

Distribution of Mass and Center of Mass

The assumption of uniform mass distribution simplifies calculations, but in practical applications, variations in material density or added components can shift the center of mass.

Implication: The actual center of mass might not be exactly at the 50-cm mark, affecting torque calculations and stability.

Structural Stability and Safety

Understanding the forces involved is critical for ensuring the structural integrity of physical systems, especially in engineering applications like cranes, balancing beams, or structural supports.

Key considerations:

- Maximum load capacity: The design must account for the maximum expected

weights and their positions.
- Material strength: Bending moments and shear forces depend on the applied torques, influencing material choice.
- Safety margins: Engineers incorporate safety factors to prevent failure under unexpected loads or dynamic factors.

Dynamic Conditions and Real-World Variations

In real systems, external factors like vibrations, wind, or sudden impacts can disturb equilibrium. Analyzing static cases provides the foundation for understanding these dynamic effects.

Educational and Practical Significance

This scenario illustrates fundamental physics principles with real-world relevance:

- Educational value: It helps students visualize forces and torques, grasp the concept of equilibrium, and perform necessary calculations.
- Design application: Engineers use similar analyses to ensure the stability of structures and mechanical systems.
- Problem-solving skills: It encourages critical thinking and precision in handling vectors, forces, and moments.

Conclusion

The examination of a horizontal meter stick supported at the 50-cm mark with a 0.5 kg mass hanging at the 20-cm mark exemplifies core principles of static equilibrium, torque, and forces. Through precise calculations, we find that the support must exert an upward reaction force of approximately 9.8 N to balance the combined weights, with the torque from the hanging mass creating a clockwise moment around the pivot.

This simple yet insightful system underscores the importance of understanding force distributions, the role of support points, and the conditions necessary for stability. Whether in educational settings or practical engineering design, such analyses form the backbone of structural mechanics, ensuring safety, stability, and efficient functioning of physical systems.

By extending this foundational understanding to more complex and dynamic systems, engineers and scientists can develop safer, more reliable structures capable of withstanding diverse forces, ultimately translating basic physics into impactful real-world applications.

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