A Meter Stick Is Supported By A Knife Edge At The 50-cm Mark And Has A Mass Of 0.40 Kg Hanging At The

A Meter Stick Is Supported By A Knife Edge At The 50-cm Mark And Has A Mass Of 0.40 Kg Hanging At The This scenario presents an interesting problem in statics and rotational equilibrium, involving a meter stick balanced on a knife edge with an additional mass hanging from it. Understanding the forces and torques involved helps illustrate fundamental principles of physics, such as torque, center of mass, and equilibrium conditions. In this article, we will explore this setup in detail, analyzing how the forces interact, calculating the torque balances, and discussing practical applications of these principles.

Understanding the Setup: The Meter Stick, Knife Edge, and Hanging Mass

The Components Involved

- **The Meter Stick:** A uniform rod measuring 1 meter (100 centimeters) in length, typically made of wood, plastic, or metal. Its mass is given as 0.40 kg.
- **The Knife Edge:** A fulcrum or pivot point supporting the meter stick precisely at the 50-cm mark, which is the midpoint of the stick.
- **The Hanging Mass:** An additional weight, which may be attached at a specific point along the stick, often at the end or at a certain distance from the support, creating a torque that affects the balance.

The Physical Principles at Play

- **Torque:** The rotational force about the pivot point, calculated as the product of the force (weight) and the distance from the pivot.
- **Equilibrium:** When the net torque about the pivot is zero, the system is in rotational equilibrium, and the stick remains balanced.
- **Center of Mass:** For a uniform stick, it is located at its midpoint; adding extra mass alters the overall center of mass.

Analyzing the Forces and Torques in the System

Basic Force Components

In this setup, the key forces include:

- **The weight of the meter stick:** Acting downward at its center of mass, located at 50 cm from either end.
- **The weight of the hanging mass:** Acting downward at its point of attachment, which could be at the end of the stick or elsewhere.
- **The normal force exerted by the knife edge:** Upward force balancing the combined weights of the stick and the hanging mass.

Torque Calculations

To understand the balance, we calculate torques about the knife edge (the pivot point at 50 cm). The torque (τ) is given by:

$$
\tau = F \times d
$$

where:
- F is the force (weight),
- d is the perpendicular distance from the pivot to the line of action of the force.

Assuming the hanging mass is attached at one end of the meter stick (say at 0 cm or 100 cm), the torques can be calculated as follows:

Scenario 1: Hanging Mass at the 0-cm End

- **Weight of the stick:** Acting at 50 cm, with a magnitude of $0.40\, \text{kg} \times 9.8\, \text{m/s}^2 = 3.92\, \text{N}$.
- **Weight of hanging mass:** Suppose the hanging mass is m_h, with a weight $W_h = m_h \times 9.8\, \text{m/s}^2$, attached at 0 cm.
- **Distance from pivot:** 50 cm to either end; for the 0-cm end, this is 50 cm or 0.50 m.

Calculating torques about the 50-cm mark:

$$
\tau_{stick} = 3.92\, \text{N} \times 0\, \text{m} \quad \text{(center of mass at pivot, thus zero torque)}
$$

$$
\tau_{mass} = W_h \times 0.50\, \text{m}
$$

Since the stick's center of mass is at the pivot, it exerts no torque about that point. The hanging mass creates a torque tending to rotate the stick clockwise or counterclockwise depending on its position.

Scenario 2: Hanging Mass at the 100-cm End

- The calculations are similar, but the distance from the pivot is now 50 cm or 0.50 m, and the torque would be:

$$
\tau_{mass} = W_h \times 0.50\, \text{m}
$$

Conditions for Balance: Achieving Rotational Equilibrium

Equilibrium Conditions

For the meter stick to be balanced on the knife edge, the net torque about the pivot must be zero:

$$
\sum \tau_{clockwise} = \sum \tau_{counterclockwise}
$$

which implies that the torques due to the hanging mass and the weight distribution of the stick must cancel each other out.

Applying the Conditions in Practice

- If the hanging mass is placed at the end of the stick (100 cm), it exerts a torque that can be balanced by shifting the position of the mass or adding additional weights.
- If the hanging mass is at the end (say at 0 cm), then the stick's own weight at the center (50 cm) does not contribute torque about the pivot, simplifying calculations.

Calculating the Center of Mass for the System

Before Adding the Hanging Mass

- The center of mass of a uniform meter stick is at its midpoint, 50 cm from either end.

- The total mass $m_{total} = 0.40\, \text{kg}$, with the center at 50 cm.

After Adding the Hanging Mass

The combined center of mass (x_{cm}) of the system can be calculated using:

$$
x_{cm} = \frac{m_{stick} \times x_{stick} + m_h \times x_h}{m_{stick} + m_h}
$$

where:
- $x_{stick} = 50\, \text{cm}$,
- x_h is the position of the hanging mass,
- m_h is the mass of the hanging weight.

Implications for Balance

- The new system's center of mass shifts toward the side with the larger mass or the mass positioned further from the pivot.
- To maintain balance, the system's center of mass must remain directly above the knife edge or the net torque must be zero.

Practical Applications and Experiments

Using the Setup to Demonstrate Physics Principles

- Educational demonstrations of torque and equilibrium concepts.
- Designing balanced beams and scales in engineering.
- Understanding the importance of center of mass in stability and balance.

Conducting Experiments

1. Place the meter stick on the knife edge at the 50-cm mark.
2. Attach the hanging mass at various points along the stick.
3. Adjust the position until the stick balances, noting the positions and masses involved.
4. Calculate torques and compare with theoretical predictions to reinforce understanding.

Conclusion

The simple setup of a meter stick supported by a knife edge at its midpoint with an additional hanging mass offers a rich context for exploring fundamental physics principles. By analyzing the forces and torques involved, students and engineers can better understand how balance is achieved and maintained in physical systems. Whether designing scales, balancing beams, or studying static equilibrium, mastering these concepts provides essential insights into the mechanics governing everyday objects and complex structures alike.

Frequently Asked Questions

How do you determine the balance point of a meter stick supported at the 50-cm mark with a hanging mass?

The balance point is found by analyzing the torques around the support point, considering the weight of the meter stick and the hanging mass; equilibrium occurs when the clockwise and counterclockwise torques are equal.

What is the torque exerted by the hanging 0.40 kg mass on the meter stick?

The torque is calculated as $\tau = r \times F$, where r is the distance from the pivot point to the mass, and F is the weight of the mass. For example, if the mass hangs at a certain point, its torque is $0.40 \text{ kg} \times 9.8 \text{ m/s}^2 \times$ distance in meters.

If the meter stick is uniform, what is its weight, and how does it affect the balance?

The weight of the uniform meter stick is its mass times gravity: $0.40 \text{ kg} \times 9.8 \text{ m/s}^2 \approx 3.92 \text{ N}$. It acts at the center of mass, at the 50-cm mark, influencing the torque balance around the support.

How can you calculate the position of the hanging mass to keep the meter stick balanced?

Set up the torque equilibrium equation considering the weights and distances from the support point, then solve for the position of the hanging mass to ensure total torque sums to zero.

What principles of physics are involved in analyzing the stability of the meter stick with the hanging mass?

The analysis involves principles of static equilibrium, torque, center of mass, and rotational dynamics, ensuring that the sum of torques and forces equals zero for the system to be balanced.

Additional Resources

A Meter Stick Is Supported By A Knife Edge At The 50-cm Mark And Has A Mass Of 0.40 Kg Hanging At The — this scenario offers a classic illustration of static equilibrium principles, torque, and force analysis. Whether you're a physics student, an educator, or a hobbyist exploring the fundamentals of mechanics, understanding the forces at play in this setup provides valuable insight into how objects balance and how to analyze real-world systems.

In this guide, we'll break down the problem step-by-step, covering the physics concepts involved, the calculations needed, and practical considerations. By the end, you'll have a comprehensive understanding of how to approach similar problems involving levers, supports, and weights.

Understanding the Scenario

Imagine a uniform meter stick — a rigid, straight object 1 meter long, with a mass of 0.40 kg — supported at its midpoint (the 50-cm mark) by a knife edge. At some point along the stick, a weight is hanging. The question often posed in such problems is: what are the forces acting on the stick? or where should the weight be placed to maintain equilibrium?

Key Elements:
- Meter Stick: Length = 1 meter (100 cm), mass = 0.40 kg
- Support: Knife edge at the 50-cm mark (center of the stick)
- Hanging Mass: Unknown position or specified position
- Gravity: Acceleration due to gravity, $g \approx 9.8 \text{ m/s}^2$

Fundamental Concepts in Static Equilibrium

Before delving into calculations, let's review the core physics principles involved:

1. Balance of Forces

In static equilibrium, the sum of vertical forces must be zero:

- The upward support force (reaction force at the knife edge)
- The downward forces (the weight of the meter stick and any additional hanging mass)

Mathematically:

`Sum of Vertical Forces = 0`

2. Balance of Torques

More crucial in this context is the torque balance about the support point:

- The net torque (moment) about the support must be zero to prevent rotation.

Mathematically:

`Sum of Torques = 0`

Step-by-Step Analysis

Let's proceed systematically:

Step 1: Assign Coordinates

Set a coordinate system along the length of the meter stick:

- Origin at the support point (the 50-cm mark)
- Positive direction to the right

In this system:
- The support is at x = 0 cm
- The left end is at x = −50 cm
- The right end is at x = +50 cm

Step 2: Determine the Weight of the Meter Stick

Since the meter stick is uniform:

- Its weight acts at its center of mass, which is at the 50-cm mark (the midpoint)
- Weight $W_s = m_s \times g = 0.40\, \text{kg} \times 9.8\, \text{m/s}^2 \approx 3.92\, \text{N}$

This weight acts downward at x = 0 cm (the center).

Step 3: Identify the Hanging Mass

Suppose the hanging mass m_h is attached at a certain point along the stick — say at position x = x_h (cm). The weight of this mass:

- $W_h = m_h \times g$

It acts downward at position x = x_h.

Note: If the problem specifies the position of the hanging mass, we'll use that. If not, the analysis can be generalized.

Step 4: Write Force Equilibrium

Vertical forces:

$$
F_{reaction} - W_s - W_h = 0
$$

Where:

- $F_{reaction}$ is the upward force exerted by the knife edge support.

Step 5: Write Torque Equilibrium

Choosing the support point (at x=0 cm) as the pivot simplifies torque calculations because the reaction force acts at the pivot and produces no torque.

Sum of torques about the support:

$$
\sum \tau = 0
$$

This leads to:

$$
W_s \times 0 + W_h \times x_h - F_{reaction} \times 0 = 0
$$

But since the support force acts at the pivot point, it produces no torque, and the torques are only due to weights:

$$
W_s \times 0 + W_h \times x_h = 0
$$

This simplifies to:

$$
W_h \times x_h = 0
$$

which suggests that if the support is at the center, the weights are balanced if they are symmetrically placed, or if the weight at some position produces a net torque that is balanced by the support's reaction force elsewhere.

Practical Example: Calculating the Hanging Position for Equilibrium

Let's consider a common problem: If a 0.40 kg mass hangs from the meter stick, at what position must it be placed so that the system is in equilibrium when supported at the 50-cm mark?

Step 1: Known Values

- $m_s = 0.40\, \text{kg}$
- $W_s = 3.92\, \text{N}$
- $g = 9.8\, \text{m/s}^2$
- Support at x=0 cm (50-cm mark)
- Mass m_h (say, 0.50 kg for a specific example)
- $W_h = 0.50\, \text{kg} \times 9.8\, \text{m/s}^2 = 4.9\, \text{N}$

Step 2: Torque Balance Equation

Taking moments about the support:

$$
W_s \times 0\, \text{cm} + W_h \times x_h = 0
$$

But since W_s acts at the support point, its torque about the support is zero. The torque due to the hanging mass is:

$$
\text{Torque} = W_h \times x_h
$$

For equilibrium (no rotation), the net torque must be zero, considering the direction:

$$
W_h \times x_h = \text{torque in the opposite direction due to the stick's weight}
$$

However, the stick's weight acts at the center, which is at the support point, so it produces no torque.

Thus, the condition simplifies to the hanging mass's torque balancing any other torques.

In this setup, the main consideration is that the support must provide an upward force equal to the total weight, and the torques of the weights must balance if the system is to remain in equilibrium.

Step 3: Solving for the Position

If the stick is uniform and supported at its center, and the only other weight is hanging at a distance x_h, the condition for equilibrium (no net torque) is:

$$
W_h \times x_h = \frac{W_s}{2} \times 0
$$

But since the stick's weight acts at the center and is supported at the same point, it contributes no torque. Therefore, the system will be balanced if the hanging weight is at the center (x=0 cm).

Alternatively, if the support is at the center, and the hanging weight is placed at some position x_h:

- For the system not to rotate, the torques must be balanced:

$$
W_h \times x_h = 0
$$

which implies $x_h = 0$, i.e., the weight must hang at the support point itself, which is trivial.

Extending the Analysis: Support Off-Center

Suppose now that the support is not at the center but at an arbitrary point, say at x = d cm from the left end. The problem then becomes more interesting:

- The weight of the stick acts at its center (x = L/2)
- The support is at position d
- The hanging mass is at position x_h

The conditions for equilibrium:

Vertical forces:

$$
F_{support} = W_s + W_h
$$

Torque balance about the support:

$$
W_s \times (d - L/2) + W_h \times (x_h - d) = 0
$$

Solving for x_h:

$$
x_h = d - \frac{W_s \times (d - L/2)}{W_h}
$$

This formula allows you to find the position x_h of the hanging mass needed for equilibrium, given the support position d.

Practical Considerations and Real-World Applications

Beyond textbook problems, this analysis has real-world implications:

- Engineering of levers and balance scales
- Designing mechanical systems with balanced loads
- Understanding the stability of structures

Factors to Consider:

- Friction at the support: In real systems, friction can affect equilibrium.
- Stick mass distribution: Non-uniform mass distribution complicates calculations.
- Support flexibility: Real supports may deform, influencing the balance.
- External forces: Wind, vibrations, or other external forces may disturb equilibrium.

Summary and Key Takeaways

- A meter stick supported at its center experiences forces that must satisfy the conditions of static equilibrium.
- The forces include the support reaction, the

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