Mass balance with a meterstick: Teaching rotational equilibrium

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Abstract

Rotational dynamics is a common topic in any undergraduate introductory physics course. While it is easy for students majoring in physics to understand the vectorial nature of quantities such as torque and moment of inertia, these concepts can be challenging to non-majors. This article describes a simple experiment that students (especially non-majors) can perform in a class to understand torque and rotational equilibrium.

Keywords: Physics education, Torque, Rotational Equilibrium.

Resumen

La dinámica rotacional es un tema común en cualquier curso introductorio de Física de pregrado. Mientras esto es fácil para los estudiantes que se especializan en la licenciatura en Física para entender la naturaleza vectorial de las cantidades como la torsión y el momento de inercia, estos conceptos pueden ser un reto. Este artículo describe un experimento sencillo que los estudiantes (especialmente para no físicos) pueden realizar en una clase para comprender la torsión y el equilibrio rotacional.

Palabras clave: Enseñanza de la Física, Torsión, Equilibrio rotacional.

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I. INTRODUCTION

Rotational motion can be found in almost every aspect of our world – the motion of a compact disc, a Ferris wheel, a ceiling fan, the blades of a chopper, atoms in a molecule, planets in our solar system, stars in the Universe – all exhibit rotational motion.

To understand rotational motion quantitatively, it is important for a student to get a grasp of basic physics concepts such as scalars, vectors, linear motion, etc [1, 2]. It is for this reason that in most introductory physics courses, rotational motion is taught almost at the end of mechanics section.

While it is easy for the students majoring in physics to understand aspects of rotational motion quantitatively, many non-majors tend to have difficulty in understanding these concepts quantitatively. For this reason, a simple activity has been demonstrated in this paper which utilizes apparatus usually available in a physics lab. This activity has been performed with two classes at Clarion University involving mostly non-majors in physics, and the results have been convincing, indicating that students gain appreciation for physical concepts through this experiment.

II. THEORY

Consider two masses hanging on either side of a meter stick hinged at the middle. A schematic diagram is shown in Fig. 1.

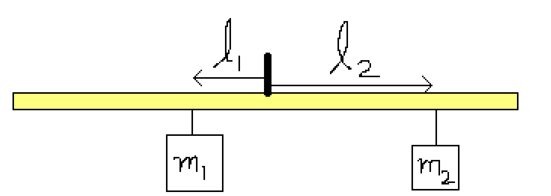

FIGURE 1. Schematic showing a meter stick with two masses attached.

The meter stick experiences two oppositely oriented torques, each of them trying to cause a rotational motion of the stick. One of them is the torque due to the mass m_1, which we shall denote as $\vec{\tau}_1$. The magnitude and direction of the torque vector $\vec{\tau}_1$ can be given by:

$$\vec{\boldsymbol{\tau}}_1 = \vec{\mathbf{l}}_1 \times m_1 \vec{\mathbf{g}}, \qquad (1)$$

where $\vec{\mathbf{l}}_1$ defines the position vector of the mass m_1 relative to the hinge, and $\vec{\mathbf{g}}$ indicates acceleration due to gravity, pointing downwards. Similarly, the torque vector $\vec{\boldsymbol{\tau}}_2$ due to the mass m_2 will be given by:

$$\vec{\boldsymbol{\tau}}_2 = \vec{\mathbf{l}}_2 \times m_2 \vec{\mathbf{g}}\,, \qquad (2)$$

where $\vec{\mathbf{l}}_2$ defines the position vector of the mass m_2 relative to the hinge.

From Eqs. (1) and (2), it is clear that for the meter stick to be in rotational equilibrium, the torques $\vec{\boldsymbol{\tau}}_1$ and $\vec{\boldsymbol{\tau}}_2$ should vectorially sum to zero, or:

$$\vec{\boldsymbol{\tau}}_1 + \vec{\boldsymbol{\tau}}_2 = 0\,. \qquad (3)$$

For Eq. (3) to be satisfied, we note that the condition to be satisfied is:

$$m_1 l_1 = m_2 l_2\,. \qquad (4)$$

The next section illustrates how the non-major students in a physics class were motivated to do this experiment to understand rotational motion concepts.

III. EXPERIMENT

The experimental setup required the following items: a meter stick, 2 small clamps to attach masses to the meter stick, a lab stand, and a few masses.

The first part of the experiment involved finding the center of mass of the meter stick. The students were asked to first of all identify a point in the meter stick where the meter stick could be balanced horizontally on just one finger. The students observed that if they tried to balance the stick at a point that is not near the center, it topples over. Eventually they found that the balancing point (center of mass) was very close to the center of the stick. They were then asked to hinge the meter stick at this point.

The students were initially given the job of balancing two *equal* masses on the meter stick. They were easily able to figure that if these masses were held exactly at the same distance on either side of the center of mass, the meter stick would be balanced. Later, they were given the interesting task: to balance *unequal* masses. After a while, they figured that they could still balance the masses, but now they had to place the masses at unequal distances. A picture of the balance by one of the student groups is shown in Fig. 2.

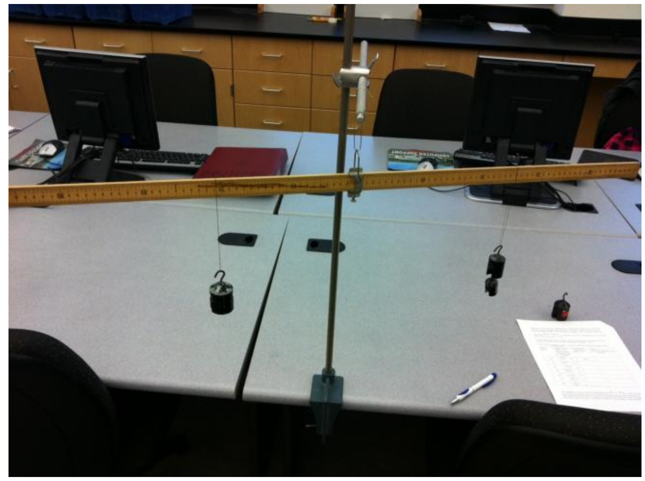

FIGURE 2. The non-major students figured out that they can balance unequal masses on a meter stick by clamping them at different distances from the center.

They now noticed that for the meter stick to be balanced, the lighter mass had to be farther from the hinge, while the heavier one had to be closer to the hinge. Now they were lectured that for the unequal masses to balance the meter stick, $m_1 l_1 = m_2 l_2$.

The students were given a mass m_1=200 grams. This was tied at a distance of l_1=20 cm from the hinge. The students were given several different masses m_2 and asked to balance each one with m_1, thereby measure the length l_2. They made a table of the obtained values of l_2, and compared it with the value of l_2 calculated from theory, $l_2 = \frac{m_1 l_1}{m_2}$. A typical table obtained by students is shown in Table I.

As a final step, the students were given an interesting task. They were provided with a known mass m_1, tied to the meter stick at a known distance l_1 from the hinge. Now they were given an unknown mass. They were asked to find the mass of this object by using the mass balance they just created.

TABLE I. Typical values of experimental data obtained by students.

Mass m_2 (grams)	Expected value of length l_2 (cm) from theory	Experimentally observed value of length l_2 (cm)
100	40	40
150	26.67	27
200	20	20
250	16	16
300	13.33	13
350	11.43	12
400	10	10

The students had to use the known and unknown masses, and balance the meter stick. Then using the formula $m_2 = \frac{m_1 l_1}{l_2}$, they had to find the unknown mass m_2. They could judge their result finally by measuring the unknown mass on an electronic scale. Typical results seen by students are shown in Table II.

TABLE II. Typical results seen by students for measuring the mass of an unknown object.

Length l_1 (cm)	Length l_2 (cm)	Calculated mass of m_2 (g) (m_1=50 g)	Expected mass of m_2 (g) (from electronic scale)
10	32.5	15.4	15.7

IV. DISCUSSION AND CONCLUSION

It can be seen from Tables I and II that the agreement between expected and observed values are excellent. At the end of the experiment, the students were convinced that they could now make a mass balance with very basic materials. This experiment was a confidence booster and a good way to get non-major students to think seriously about physics concepts.

ACKNOWLEDGEMENTS

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