Torques and Equilibrium

Goal: To test the condition of static equilibrium by summing torques.

Lab Preparation
There are two main things to review for this lab.

First, understanding how to find the magnitude of the torque on an object, $\tau = F\ell$, and knowing how to find the moment arm ℓ is very important. Remember, the moment arm is the shortest distance between the axis of rotation and the line of action (Figure 1). If $\theta = 90^{\circ}$ then the moment arm is equal to r, the distance from the axis to where F is applied.

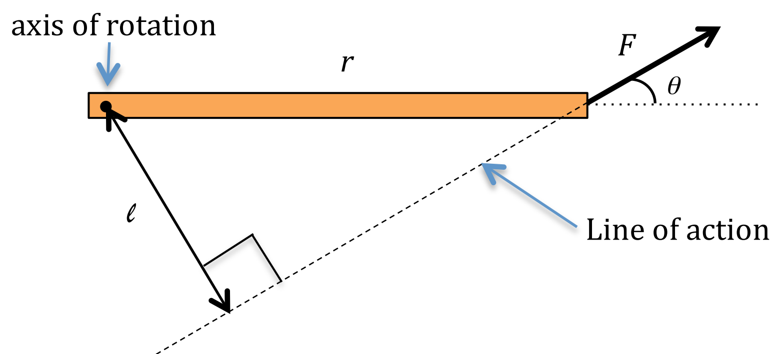

Figure 1

Second, the conditions for an object to be in static equilibrium are:

$$\Sigma F = 0$$
$$\Sigma \tau = 0$$

For this lab these conditions will be met. When $\Sigma\tau = 0$ this means that the counterclockwise torques (positive) must balance the clockwise torques (negative). Reviewing problems of this type will be helpful for this lab.

Equipment
A meter stick with different masses attached to it will be the main equipment for this lab.

Procedure

I. Center of mass of a meter stick

Support the meter stick with its sliding 'knife-edge' attachment on the metal stand. Slide the meter stick through the knife-edge until it balances. Clamp the knife-edge to the meter stick and leave it there for the rest of the lab. The center of mass is at the knife-edge. Record the meter stick reading at this point.

II. Finding the mass of the meter stick by using torques

Insert a nail through the meter stick at the 75 cm point and rest the meter stick in the stand at this point. Find experimentally where a mass m = 300 g should be hung by a loop of thread from the meter stick to make it balance (see Figure 2).

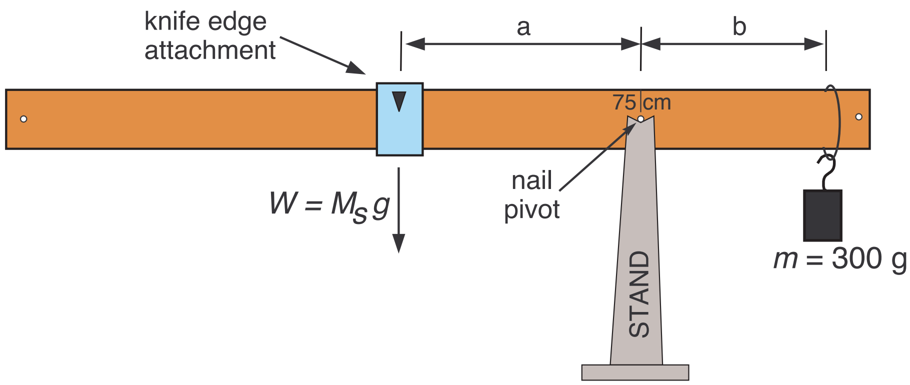

Figure 2

By placing m in this position you are balancing the torques on the meter stick. Thus, the meter stick is put into a condition of static equilibrium. If the axis of rotation is chosen to be at the 75 cm position then the clockwise torque produced by m must balance out the counterclockwise torque produced by the meter stick (here we are taking the mass of the meter stick and knife edge to act at its center of mass with a mass = M_s).

Measure and record the distances a and b shown in Figure 2. Find M_s by summing torques around the axis of rotation.

Now find the mass (M) of the meter stick (with knife edge) directly on a scale and record. Find the % difference between this value (the expected value) and M_s (the experimental value) using:

$$\frac{|Experimental - Expected|}{Expected} \text{ x } 100\%.$$

III. Finding the moment arm of a force

Again support the meter stick on the nail at the 75 cm point. Hang $m_1 = 500$ g exactly at the 95 cm point. Experimentally find where $m_2 = 100$ g should hang from the meter stick to balance the meter stick (see Figure 3). Record the experimental value of x.

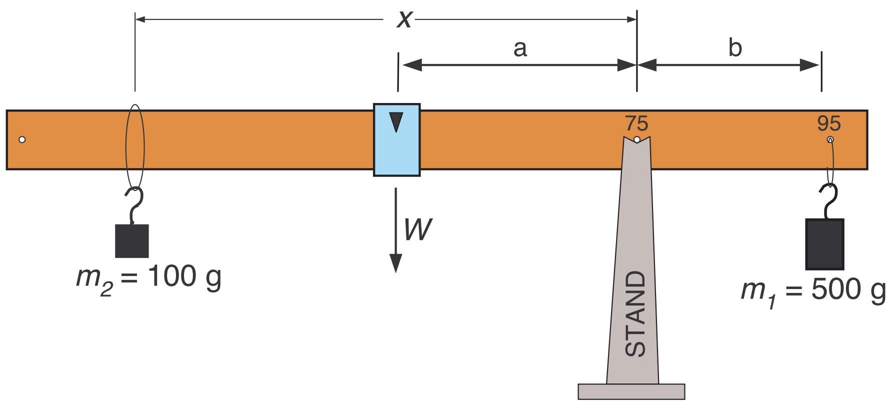

Figure 3

Taking the axis of rotation to be the 75 cm mark again, the torque produced by m_1 must balance out the torque produced by m_2 and M. Knowing a, b, m_2, M, and m_1 you can calculate the expected value of x by summing torques around the axis of rotation. Calculate x and report the percentage difference between the expected (calculated) and experimental values.

IV. Finding force produced using torques

With the meter stick still supported at the 75 cm point, support the meter stick near the other end at the 10 cm point by resting it on one edge of a small wooden prism as shown in Figure 4. The prism rests on a scale. You can measure the upward force F_B (the scale will actually measure grams) that the prism exerts on the meter stick.

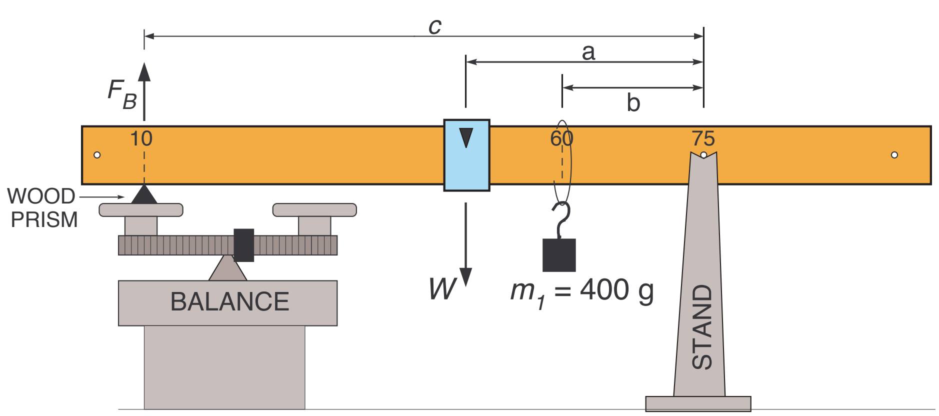

Figure 4

Hang $m_1 = 400$ g exactly at the 60 cm point. Adjust the meter stick so it is nearly horizontal. You may need to raise the scale or stand by placing a book or two underneath it. Record the scale reading. Measure the mass of the small wooden prism and subtract this from the scale reading to find the experimental value of F_b in grams.

Once again take the axis of rotation to be the 75 cm point. Sum torques and calculate the expected value of F_b and also find the % difference between the expected and experimental values.

V. <u>Finding moment arm for forces at an angle</u>
Hang the meter stick at the 1 cm point on a nail (in a wooden dowel) on a tall stand. Another string hangs vertically downward from the nail to serve as a plumb line. Arrange a pulley and mass $m = 100$ g as shown in Figure 5 to apply a force at right angles to the meter stick at the 60 cm point. Use the edges of a sheet of paper to test that you have a right angle between the string going to the pulley and the meter stick.

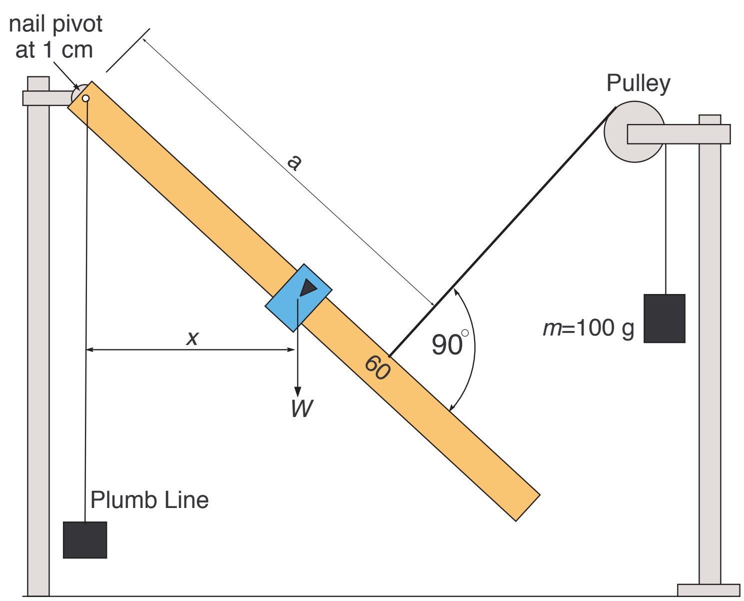

Figure 5

Measure x, the moment arm due to the weight of the meter stick, from the plumb line to the center of mass of the meter stick.

Letting the axis of rotation be at the 1 cm point, the torque produced by the string (attached at the 60 cm point) must be balanced out by the torque produced by the weight of the meter stick. Sum torques about this axis and calculate the expected value of x. Find the % difference between expected and experimental values of x.

VI. <u>Finding the angle for a force</u>
As in part V hang the meter stick by the nail at the 1 cm point. Put a string through the hole at the 99 cm point and lead the string around the pulley on the other stand as shown in Figure 6.

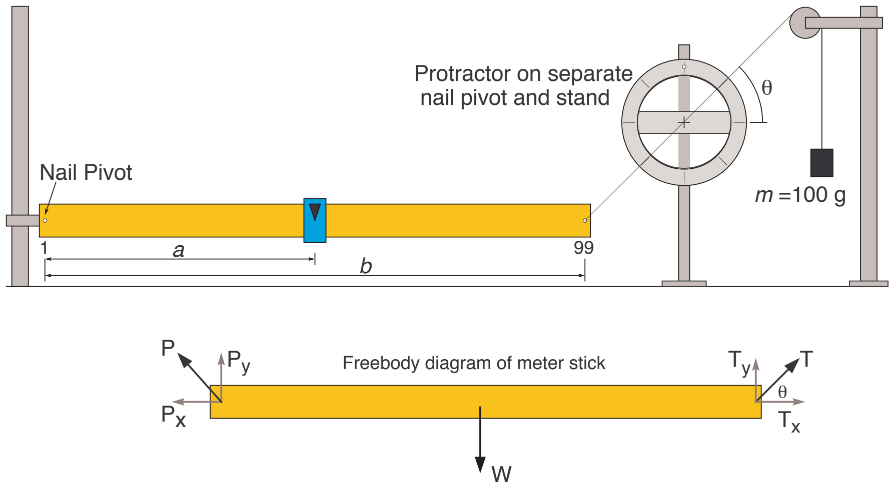

Figure 6

Place a 100 g mass at the end of the string over the pulley and adjust the position of the pulley to place the meter stick in a horizontal position. One way to determine when the meter stick is in the horizontal position is to use the top or bottom line of the blackboard as a horizontal reference line and stand back a meter or more from the meter stick and align the meter stick with the blackboard line. Position the protractor mounted on a separate stand (use another dowel-mounted nail to hold the protractor) to measure the angle θ of the string with respect to the horizontal. Record the value of θ.

To calculate the expected value of θ you once again will want to apply the conditions for static equilibrium. A free body diagram of the meter stick is shown in Figure 6. Selecting the axis of rotation at the 1 cm mark will eliminate any torques produced by the pivot (force P) and thus, the torque produced by the weight of the meter stick must be balanced out by the torque produced by the string attached at the 99 cm point. Use this information to help calculate the expected value of θ. Check to see if this is close to your measured value of θ.

When finished with your lab please make sure your lab station is cleaned up.

<u>Homework</u>

1. For part VI draw a picture showing where the moment arm is located for the tension T and then calculate this moment arm value.

2. For part VI calculate the predicted values of P_x and P_y in grams.