Torque and Rotational Equilibrium

Name:______________________________ Date:____________ Group #:_____

Lab Partner:____________________________

Objectives:
- To learn to calculate torques about an axis.
- To learn to apply the principle of rotational equilibrium.

Materials Needed:
- Meter stick
- Three 50 g hanging masses
- Mass set
- Lab stand
- Lab clamp
- Four hook clamps
- Electronic Mass Balance

Theory:

Torque and Rotational Equilibrium

The torque exerted by a force about an axis is equal to

$$\vec{\tau} = \vec{r} \times \vec{F}$$

This cross-product formula means that (i) the magnitude of the torque is given by

$$\tau = rF \sin \phi$$

and (ii) the direction is given by the Right Hand Rule.

If an object is in rotational equilibrium, the net torque on the object is zero.

$$\Sigma\vec{\tau} = 0$$

In this lab, you will be hanging masses from a meter stick at specific locations. You will then, by trial and error, find a location to hang a final mass (called the balancing mass) to cause the meter stick to achieve equilibrium.

Procedure:

1. Measure the mass of your meter stick. Record its value: $m_{stick} =$ _______________ g

2. Find the location of the center of mass of your meter stick using the following method:

   a) Slide the meter stick into a hook clamp such that the center of the clamp is at 50.0 cm, and the hook is facing up. Then tighten the clamp on the stick.

   b) Hang the hook from the lab clamp attached to the lab stand and hold it horizontally.

   c) Release the stick. If it remains horizontal (does not rotate), then 50.0 cm is the location of the center of mass of the stick.

   d) If the meter stick does rotate, then move the hook clamp slightly to find a location where the meter stick does not rotate. This will be your center of mass.

   e) Record your center of mass location below, to the nearest mm (1/10th of a cm).

$x_{cm} =$ _________________________ cm

<u>Experiment 1</u>

1. Gather a hook clamp, a 50 g hanging mass, and a 100 g mass from your mass set. Measure the mass of all three combined. Call this m_1 and record it in Data Table 1.

2. Take another hook clamp, a 50 g hanging mass and a 150 g from your mass set. Measure the mass of all three combined. Call this m_{bal} and record it in Data Table 1.

3. Put the first hook clamp (part of m_1) on the meter stick, hook side down, at the 10.0 cm mark on the stick and tighten it. Then hang the 50 g and 100 g mass from it.

4. By trial and error, determine where to hang m_{bal} such that you can let go of the stick and it will stay completely horizontal. Enter this location in Data Table 1 as $x_{bal,exp}$.

5. Note that $x_{bal,exp}$ is not the lever arm, it is simply the location (relative to 0 cm) on the stick. Find the lever arm of the balancing mass and enter this as $r_{bal,exp}$ in Data Table 1.

<u>Experiment 2</u>

1. Leave m_1 exactly where it is (at the 10.0 cm mark). Record its mass in Data Table 1.

2. Move the mass that was the balancing mass in Experiment 1 to the 60.0 cm mark. Call this m_2 and record its mass in Data Table 1.

3. Make a balancing mass out of yet another hook clamp, a 50 g hanging mass and another 50 g mass from the mass set (for a total of 100 g plus the hook clamp). Measure the mass of the hook clamp plus the 100 g and enter it as m_{bal} in Data Table 1.

4. By trial and error, determine where to hang m_{bal} to achieve equilibrium. Enter this location in Data Table 1 as $x_{bal,exp}$.

5. Find the lever arm of the balancing mass and enter this as $r_{bal,exp}$ in Data Table 1.

<u>Experiment 3</u>

1. Leave m_1 exactly where it is (at the 10.0 cm mark). Record its mass in Data Table 1.

2. Remove m_2 and m_{bal} from the stick.

3. <u>Slide the clamp that was at the center of mass to the 30.0 cm mark. Note that the axis is no longer at the center of mass.</u>

4. Form a balancing mass out of a hook clamp, a 50 g hanging mass and 150 g of additional mass. Measure the mass and record the mass value as m_{bal} in Data Table 1.

5. By trial and error, determine where to hang m_{bal} to achieve equilibrium. Enter this location in Data Table 1 as $x_{bal,exp}$.

6. Find the lever arm of the balancing mass and enter this as $r_{bal,exp}$ in Data Table 1.

Data Table 1

Experiment	m_1 (g)	x_1 (cm)	m_2 (g)	x_2 (cm)	m_{bal} (g)	$x_{bal,exp}$ (cm)	$r_{bal,exp}$ (cm)
1		10.0	N/A	N/A			
2		10.0		60.0			
3		10.0	N/A	N/A			

<u>Calculations</u>

First, re-write your experimental lever arm values in the $r_{bal,exp}$ column in Calculation Table 1.

Calculation Table 1

Experiment	$r_{bal,exp}$ (cm)	$r_{bal,theo}$ (cm)	% error
1			
2			
3			

1. For Experiment 1, use the values of m_1, x_1, m_{bal} and the location of the axis to calculate the theoretical lever arm for the balancing mass.

   Show all work clearly below, using the idea of torques and equilibrium. Your work *must* include a correct extended force diagram of the stick.

   Write your answer clearly after your work and then enter your answer in the $r_{bal,theo}$ entry for Experiment 1 in Calculation Table 1.

2. For Experiment 2, use the values of m_1, x_1, m_2, x_2, m_{bal} and the location of the axis to calculate the theoretical lever arm for the balancing mass.

   Show all work clearly below, using the idea of torques and equilibrium. Your work *must* include a correct extended force diagram of the stick.

   Write your answer clearly after your work and then enter your answer in the $r_{bal,theo}$ entry for Experiment 2 in Calculation Table 1.

3. For Experiment 3, use the values of m_1, x_1, m_{bal}, m_{stick}, the location of the center of mass and the location of the axis to calculate the theoretical lever arm for the balancing mass.

   Show all work clearly below, using the idea of torques and equilibrium. Your work *must* include a correct extended force diagram of the stick.

   Write your answer clearly after your work and then enter your answer in the $r_{bal,theo}$ entry for Experiment 3 in Calculation Table 1.

4. Calculate the percent errors for the measured values and enter them in the Calculation Table.

Questions

1. What are the two requirements for an object to be in mechanical equilibrium (this includes translational equilibrium and rotational equilibrium)?

2. The mass of the axis hook clamp was not measured. Why did you not need the value of the mass for this lab? Explain.

3. For the first experiment, determine the upward force (exerted by the lab clamp) required to keep the stick in translational equilibrium? (Ignore the small mass of the axis clamp).

4. Discuss the accuracy of your experiments. Include percent error values in your discussion. What factors could have caused errors in this lab? (Saying "human error" is not enough. You must discuss specific factors)

<u>What to Turn In</u>: Each individual must submit in Canvas:

1. A pdf or word document containing pages 1-6 of the lab, with all data tables filled in, calculations shown, and questions answered.