Torque

Goals and Introduction

When a force is exerted an object, it is possible that the force not only causes the object to undergo a translational acceleration, but also rotate! The ability of a force to cause rotation is called "torque," and is measured in the SI units of N·m. Figure 1 gives us an example for thinking about the quantities needed for measuring torque due to a force: 1) w, the distance from the pivot point to where the force is applied, 2) F, the magnitude of the applied force, and 3) θ, the angle between a position vector from the pivot to the force location, and the force itself. **In this experiment, we will assume that angle is 90°.** The relationship resulting in torque is seen in Equation 1.

$\tau = wF \sin\theta$ (Eq. 1)

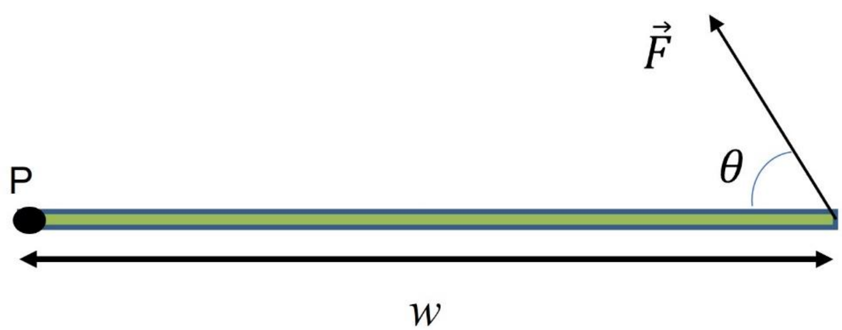

Figure 1

When several forces act on an object, the net torque can be found by comparing the torques that would cause clockwise rotation, to those that would cause counterclockwise rotation. In this experiment, the pivot point will be the balance point in the center of a half-meter stick, and forces will act downwards. Thus, forces on the left side of the stick would tend to make it rotate counterclockwise, and those on the right side of the stick would tend to make it rotate clockwise.

We will use hanging objects to create an equilibrium state for the system, where there is no net torque. For equilibrium, the sum of the clockwise torques (right side of stick) should be equal in magnitude to the sum of the counterclockwise torques (left side of stick).

Goals: (1) Develop a better understanding of torque and rotational equilibrium.
(2) Use the system of objects in the lab to determine the mass of an object.

<u>Procedure</u>

Equipment – half-meter stick, 4 brackets, 3 mass hangers, 2 50-g hanging masses, 1 100-g hanging mass, 1 hanging object of unknown mass, stand, balance

1) Slide the bracket with no mass holder onto the half-meter stick and **lightly** pin it somewhere near the middle of the stick. Then, place it on the stand to see if it balances. Try adjusting the location of the holder on the stick until you get the stick to balance in the stand. Then, tighten this bracket a little, so it won't slide. If you are struggling to get the balanced state, get it as close as possible to a balanced state. **Measure and record** the location of the bracket. This is the location of the center-of-mass, or **balance point** of the stick, with nothing hanging on it. Keep this bracket at its location during the experiment.

2) **Measure and record** the mass of one of the brackets with the mass holder.

Trial A:

3) Use one of the other brackets to hang a 50 g object about 10 cm away from the balance point, on the left side. **Measure and record** the location of this first bracket.

4) Then, use another bracket and the second 50 g object on the right side of the stick to create a balanced state. Hang this object on the right side, hold the stick horizontally, and let go to see if it balances. Adjust the location of this bracket on the right side and try again, until it balances. **Measure and record** the location of this second bracket.

5) **Compute and record** the total mass at each location (remember to include the bracket!), and the distance of each bracketed hanging object from the balance point.

Trial B:

6) Leave the first 50 g object in place on the left side. Take off the 50 g object from the right side and replace it with the 100 g object. Adjust the location of the bracket on the right side until the system balances again. **Measure and record** the location of this second bracket.

7) **Compute and record** the total mass at each location, and the distance of each bracketed hanging object from the balance point.

Trial C:

8) Leave the first 50 g object in place on the left side. Use a hanging bracket to place the second 50 g object on the left side of the stick, so that it is about 20 cm away from the balance point. **Measure and record** the location of this second bracket.

9) Use the 100 g object and the third bracket on the right side of the stick. Adjust the location of this bracket on the right side until the system balances again. **Measure and record** the location of this third bracket.

10) **Compute and record** the total mass at each location, and the distance of each bracketed hanging object from the balance point.

Trial D:

11) Keeping the balance point bracket in place, remove the other hanging brackets and objects. Then, use one of the hanging brackets to hang the object with an unknown mass about 10 cm from the balance point. **Measure and record** the location of this first bracket.

12) Then, use another bracket and the 100 g object on the right side of the stick to create a balanced state. Hang this object on the right side, hold the stick horizontally, and let go to see if it balances. Adjust the location of this bracket on the right side and try again, until it balances. **Measure and record** the location of this second bracket.

13) **Compute and record** the total mass on the right side, and the distance of each bracketed hanging object from the balance point. This data will be used to predict the mass of the unknown object in analysis.

14) Use the balance to **measure and record** the mass of the unknown object for later comparison to our prediction.

Data and Error Analysis

Trial A:

Use the total mass at each location to calculate the magnitude of the gravitational force acting on each object. We then assume these are the forces applied at their respective locations.

Use the force and distance from the balance point at each location to calculate the torque due to each hanging object.

$$\tau = wF \sin 90^{\circ}$$

Identify each torque as being applied on the left side, or right side of the stick. Determine the total torque on the left side and the total torque on the right side of the stick. Use these to compute the percent difference between the total torque on the left side and the total torque on the right side.

$$\%diff = \frac{|\tau_{left} - \tau_{right}|}{\left(\frac{(\tau_{left} + \tau_{right})}{2}\right)} \times 100\%$$

Trial B:

Use the total mass at each location to calculate the magnitude of the gravitational force acting on each object.

Use the force and distance from the balance point at each location to calculate the torque due to each hanging object.

Identify each torque as being applied on the left side, or right side of the stick. Determine the total torque on the left side and the total torque on the right side of the stick. Use these to compute the percent difference between the total torque on the left side and the total torque on the right side.

Trial C:

Use the total mass at each location to calculate the magnitude of the gravitational force acting on each object.

Use the force and distance from the balance point at each location to calculate the torque due to each hanging object.

Identify each torque as being applied on the left side, or right side of the stick. Determine the total torque on the left side and the total torque on the right side of the stick. Use these to compute the percent difference between the total torque on the left side and the total torque on the right side.

Trial D:

Use the total mass on the right side (where the 100 g object was located) to calculate the magnitude of the gravitational force acting on that total mass.

Use the force and distance from the balance for the 100 g object to calculate the torque due to that hanging object.

Assuming the torque on the left, due to the object with unknown mass, is equal in magnitude to the torque on the right, calculate the gravitational force that must be acting on the unknown mass, and its hanging bracket.

$$\tau = wF \sin 90^{\circ}$$

Use that gravitational force to calculate the total mass at that location.

Subtract the mass of the hanging bracket to determine the unknown mass.

Compare this calculated result to the value you measured and recorded for the mass of the unknown object by calculating the percent error. Treat the measured value from the balance in the procedure as the accepted value.

$$\%err = \left| \frac{x_{\text{calculated}} - x_{\text{accepted}}}{x_{\text{accepted}}} \right| \times 100\%$$

Questions and Conclusions

Q1: Was equilibrium achieved in each scenario? How do the analyses support your answer?

Q2: Evaluate your results finding the unknown mass. Was the experimental process using the half-meter stick and the brackets able to accurately determine the value of the unknown mass? Was it okay to assume the torque due to the unknown mass was the same as the other torque? Explain your answers.

Q3: What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

Trial A:

Mass of hanging bracket (kg):				Location of balance point (m):			
	mass (kg)	**location (m)**	**total mass (kg)**	***w* (m)**	***F* (N)**	***τ* (N·m)**	**left or right?**
#1							
#2							
Percent Difference:							

Trial B:

Mass of hanging bracket (kg):				Location of balance point (m):			
	mass (kg)	**location (m)**	**total mass (kg)**	***w* (m)**	***F* (N)**	***τ* (N·m)**	**left or right?**
#1							
#2							
Percent Difference:							

Trial C:

Mass of hanging bracket (kg):				Location of balance point (m):			
	mass (kg)	**location (m)**	**total mass (kg)**	***w* (m)**	***F* (N)**	***τ* (N·m)**	**left or right?**
#1							
#2							
#3							
Percent Difference:							

Trial D:

Mass of hanging bracket (kg):				**Location of balance point (m):**		
	mass (kg)	**location (m)**	**total mass (kg)**	***w* (m)**	***F* (N)**	**τ (N·m)**
#1	[redacted]		[redacted]		[redacted]	[redacted]
#2						
Measured mass of unknown object:						
Calculated mass of the unknown object:						
Percent Error:						