PHYS 1405 – Conceptual Physics 1
Laboratory #7
Rotational Motion

Investigation: How can we use the idea of torque to get things to balance?

What to measure: Torques caused by various forces.

Measuring devices: Computer simulation, meter stick with weights

Calculations: Torque, mass of a hanging weight, position of a hanging weight.

INTRODUCTION

In this lab, we revisit the idea of equilibrium, this time incorporating the idea of the torques produced by forces. According to Newton's First Law, if the forces acting on an object are in balance, the object's motion will not change:

- If the vertical forces are in balance, the vertical motion will not change.
- If the horizontal forces are in balance, the horizontal motion will not change.

Now we can add a third statement:

- If the torques are in balance, the object's spinning motion will not change. If it is spinning, it will keep spinning as it is. If it is not spinning, it will stay where it is and not spin.

If a force causes something to spin, we say that it causes a torque. If the force is applied at a 90-degree angle, the size of the torque depends on the size of the force, and the distance of that force from the axis of spin:

Torque = (Size of force) (Distance of force from axis)

Notice that this means that a force applied at the axis causes no torque. Torques have a positive sign if they cause an object to spin counterclockwise, and a negative sign if they make the object spin clockwise.

Part 1 – Computer Simulation of Equilibrium

In the computer simulation, you see three weights hanging from a meter-long stick. The stick is supported by a fulcrum at its center. The meter stick has a mass of 200 grams. The 50-gram cube is hanging from the left end of the meter stick. A 20-gram cube is hanging 10 centimeters from the right end. A third cube hangs 20 centimeters from the center of the stick. We do not know the mass of this cube, but we can find it out.

Question 1: What is the distance of the "mystery cube" from the axis?

First, we set the axis of rotation at the Point A, which is at the center of the meter stick. Fill out the table below, using a value of 9.8 m/s^2 for g in the weight formula:

Object	Weight Force (in N)	Distance from Axis (m)	CCW (+) or CW (-)?	Torque (in Nm)
50-gram cube				
20-gram cube				
Total Torque of both cubes				

Question 2: How much torque must the third cube cause to balance the combined torque of the other two and keep the stick in balance? What sign must it have?

Question 3: What weight and mass must the mystery cube have to achieve this torque?

In the simulation, set the mass of the mystery cube to this value, and hit run.

Question 4: Is the stick in equilibrium? Do the torques you calculated agree with the figures on the screen?

Part 2 – Changing the Axis

You can also change the position of the axis of rotation. This will not change the weight of each cube, but it will chance the distance of each of these weight forces from the axis. Therefore, the torques will change. Imagine that you move the axis to a position 10 centimeters to the right of the center, but do not move the cubes *or the fulcrum*. Recalculate the torques for each of the cubes, and fill out the table below:

Object	Weight Force (in N)	Distance from Axis (m)	CCW (+) or CW (-)?	Torque (in Nm)
50-gram cube				
20-gram cube				
Mystery cube				
Total Torque of all three cubes				

Question 5: Based on these figures, would you expect the stick to still be in equilibrium? Why or why not?

Question 6: With the axis in its new position, hit "Run." Are the numbers in your table confirmed? What about your answer to Question 5?

The stick is in equilibrium still, regardless of the fact that the torques from the three cubes do not add to zero. This means that there are now some torques in play now that weren't around before. One of these is the torque caused by the weight of the meter stick, which acts at the very center of the stick.

Question 7: Why didn't the weight of the stick cause a torque at the beginning of the exercise?

Fill out this table again:

Object	Weight Force (in N)	Distance from Axis (m)	CCW (+) or CW (-)?	Torque (in Nm)
50-gram cube				
20-gram cube				
Mystery cube				
Weight of Stick				
Total Torque of all three cubes plus the Torque of the meter stick				

The total torque is still not zero! There is yet another force that didn't cause a torque last time, but is doing so now that we have moved the axis. This is a fifth force that acts on the meter stick.

Question 8: What is this unaccounted-for force? How much torque does it cause, and in what direction? Remember that it must balance all the other torques combined!

Question 9: How big must this fifth force be to cause this much force?

Draw a diagram of the meter stick, showing all five forces acting on the stick. Be careful to show exactly where each force acts!

Question 10: Since the meter stick is not moving upward or downward, how big must this fifth upward force be to balance the other four downward forces? How does your answer match up with the answer to Question 9?

Part 3 – Balancing a Real Meter Stick

Now we'll work with the real thing. We begin with a meter stick hanging from a force sensor. The meter stick begins by being balanced.

Question 11: In our exercises, we usually assume that the meter stick would have a uniform distribution of mass. Is that true for our real-world meter stick? Justify your answer.

Hang a 100-gram mass from the 90-cm mark of the meter stick. Note that the stick becomes unbalanced.

Question 12: What is the size and direction of the torque caused by the 100-gram mass? Show your calculations. Remember that the holder has mass!

Question 13: What is the size and direction of the torque caused by the weight of the meter stick? Justify your answer.

Question 14: What other force causes a torque identical in size and direction to the torque in Question 13? Justify your answer.

Imagine that a 200-gram mass is hung on the other side of the meter stick to bring it back into balance. Draw a force diagram showing all the forces acting on the meter stick.

Question 15: Where must a 200-gram mass be hung to bring the meter stick back into balance? Show your calculations.

Hang a 200-gram mass at the location that you calculated. Make minor adjustments until the meter stick actually comes into balance. Calculate the percentage difference between your predicted and actual values for the position using the formula

$$\%\,Difference = \frac{computed\ position - actual\ position}{actual\ position} \times 100\%$$

Question 16: Remembering that a 15% difference is pretty good for our equipment, did your calculations accurately predict the position of the 200-gram mass? Justify your answer.