

Physics 200B Lab 11

Torque and static equilibrium

Objectives:

To investigate the properties of the center of mass of an object

To investigate the properties of torque

To apply the conditions for static equilibrium to an object acted on by a number of forces.

Overview:

For a rigid object to be in equilibrium (acceleration = 0 and angular acceleration = 0), the net force on it has to be zero, and the net torque due to those forces also has to be zero around any axis of rotation.

In this lab, the rigid object is a meter stick supported at a pivot point. If the meter stick is in equilibrium, then the magnitude of the net negative (or clockwise) torque around that pivot should be equal to the net positive (or counterclockwise) torque about that pivot. We'll investigate this for several different setups, one of which models a situation based on human anatomy.

Note 1: It is important to remember that two measured quantities agree with each other only if their error ranges overlap! Thus, the error analysis in this lab is important.

Note 2: As in the force table experiment, the friction in the pulleys can be non-negligible. You will want to develop a procedure for making sure that friction doesn't give you erroneous results.

Note 3: The forces used in this experiment are all weights, equal to mg . If you are careful in how you set up a calculation, often the factor of g will drop out, which makes things somewhat simpler. However, please recall that forces are measured in newtons and mass in kilograms.

Activity 1:

Find the center of mass of your meter stick by putting the pivot clamp at 50.0 cm and hanging the stick from it. Move the pivot around until the stick hangs in equilibrium. Do this carefully, and record the measured position of the center of mass. Then determine the uncertainty (+/-) in the center of mass position by seeing how far to either side you can move the pivot and have the stick still be in equilibrium. Record your results below:

Question 1: Draw a free-body diagram of the meter stick when it supported at its center of mass, including all forces acting on it. Use your diagram to explain carefully why finding the point at which the meter stick balances is equivalent to finding its center of mass position. (Hint: if the point of support is not at the center of mass position, what is the net torque about an arbitrary axis?)

! Checkpoint 1

In the activities that follow, remember that the meter stick still has mass, and so its weight must be considered as one of the forces acting on it. Remember that the weight acts at the center of mass position. Also, don't forget about the mass of the clamps!

Activity 2:

Place the pivot clamp at the center of mass position and balance the stick there. Place a downward load of 150 g at the 10 cm mark by hanging mass directly from a clamp at that point. (Record masses and locations as precisely as you can determine them.) Now you will place another downward load at the 70 cm mark in order to make the stick balance in equilibrium. First draw a free-body diagram of the stick, and use it to predict how much mass you will have to use. (Write down the net counterclockwise torque about the pivot and the net clockwise torque about the pivot, set them equal to each other, and solve for the mass.)

Now find experimentally how much mass is needed at 70 cm to balance the stick. Then determine an error range for this result by first adding and then subtracting mass to find the largest and smallest masses for which the stick will be in equilibrium. Record your results.

Question 2: Does your prediction work? Comment.

Activity 3:

Keep the setup the same, but predict how much mass you will have to use to balance the meter stick if the mass is placed at 80 cm instead of 70 cm. Explain your reasoning.

Now try it with the mass you just predicted would work. What is the result? If it doesn't come out the way you predicted, find the mass needed by trial and error, and then explain why that mass is needed.

! Checkpoint 2**Activity 4:**

Place the pivot clamp at 10 cm and put an upward force near 60 cm, using a pulley and a hanging weight. Determine the mass needed to hold the meter stick level and the uncertainty in this mass. Also record any uncertainties in the positions.

Question 3: From this information, determine the mass of the meter stick. Show your calculations and your result along with its uncertainty.

Question 4: Using an electronic balance, find the mass of your meter stick and the associated uncertainty. Do the two measurements agree? Why or why not?

! Checkpoint 3

Activity 5:

Keep the setup the same but move the upward force from 60 cm to 80 cm. Predict how much mass you will have to use (to create the upward force at 80 cm) to balance the meter stick if an additional mass of 200 g is placed at 40 cm. Explain your reasoning.

Now try it. What is the result? If it doesn't come out the way you predicted, find the mass needed by trial and error, and **then explain why that mass is needed.**

! Checkpoint 4**Activity 6:**

Set up the meter stick with the pivot near 2.0 cm, and place a downward load of about 100 g near 90.0 cm (record the positions as precisely as you can). Now place an upward force near 25.0 cm. Note that supporting the pivot by hanging it from the top no longer works! Find a way to support the pivot, and then adjust the upward force at 25 cm in order to place the stick in equilibrium. Draw a free-body diagram of the situation, labeling all forces.

Experimentally determine the upward force required at 25 cm to balance the meter stick in equilibrium. Also determine the uncertainty in the upward force required at 25 cm by adding and subtracting mass till the meter stick is no longer in equilibrium. Record your results.

Using the measured values and the free-body diagram, calculate the total clockwise torque and its experimental uncertainty; then calculate the total counterclockwise torque and its uncertainty. Is the net torque about the pivot point zero (within uncertainty ranges)? Explain.

Question 6: Find the value of the force exerted on the pivot point. (Hint: the net force on the meter stick must also be zero!)

Question 7: The situation in this activity is a model for the forces on your forearm when it is held horizontally, with a weight in the hand. The pivot represents the (downward) force exerted by the elbow joint; the upward force at 25.0 cm represents the force exerted on the arm by the bicep muscle; the mass of the meter stick represents the mass of the forearm; and the downward force near 90 cm represents a weight held in the hand. What do your results tell you about the size of the forces exerted by your muscles and joints, in comparison to the weight itself?

! Checkpoint 5