Torque and Equilibrium

Name ________________________

Equipment Used;

Meter sticks
hanging masses
Force sensors
Laptop computers
Lab Pro
Triple beam balance

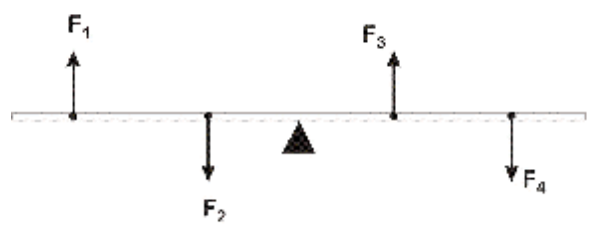
Rev Fall, 2011

Purpose:

The purpose of this lab is to examine the role of torque in static equilibrium. You know that if an object is not moving, then the vector sum of the external forces is zero. But depending on the number of forces acting on the object, this may not be enough information to determine the value of all of the individual forces. But if the object is not rotating then the vector sum of the torques is also zero. This gives you another set of relations to use to solve for all the unknown forces.

Part 1:

For linear motion the application of two forces can result in equilibrium if they act in opposite directions. Torques can result in equilibrium when they act to rotate the object in opposite senses. It is also important to be clear about the axis of rotation.



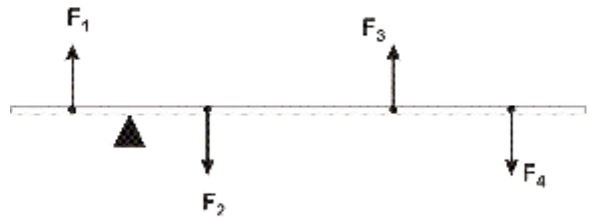
The sketch on the right shows 4 forces acting on a board. The board is supported in the center and we will consider that to be the point or axis about which the board would tend to rotate under the action of these forces.

Our convention is that we will label torques that would tend to rotate the object counter clockwise as positive. Torques that would tend to make the object rotate clockwise we will label as negative.

Using this convention forces $\mathbf{F}_2$ and $\mathbf{F}_3$ create positive torques and $\mathbf{F}_1$ and $\mathbf{F}_4$ create negative torques. Note that whether the torques are positive or negative depends on the position of the axis of rotation.

The next sketch shows the same arrangement of forces but with a different support point.

Assuming that the support point is the axis of rotation, identify the sign of each of the four torques created by the four forces.



Torque 1 is ☐ positive ☐ negative

Torque 2 is ☐ positive ☐ negative

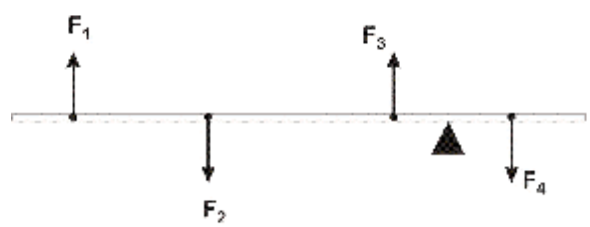
Torque 3 is ☐ positive ☐ negative

Torque 4 is ☐ positive ☐ negative

Which of the 4 torques has changed signs compared to the original sketch?

Look at one more variation on this next sketch

Assuming again that the support point is the axis of rotation, identify the sign of each of the four torques created by the four forces.



Torque 1 is ☐ positive ☐ negative

Torque 2 is ☐ positive ☐ negative

Torque 3 is ☐ positive ☐ negative

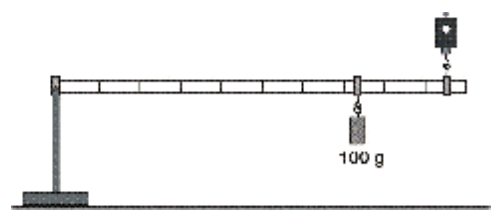
Torque 4 is ☐ positive ☐ negative

Which of the 4 torques has changed signs compared to the original sketch?

Question 1: The same force acting on a specific object will not always produce a torque of the same sign (positive or negative)? Point to several specific examples from the above cases to support your answer and explain how this can happen.

Part 2:

Let's look at a simple arrangement using the meter stick.



1. Determine the mass of the meter stick and record the value in data table 1 on page 4
2. Boot the laptop computers and start Logger Pro
3. Power up the Lab Pro and connect the force sensors to channels 1 and 2. Make sure the switch on the force sensor is set to the 10 Newton position. Under Experiment on the Logger Pro menu choose Set up Sensors. From the list of sensors along the left hand side choose the dual range force sensor and drag and drop it to both channels 1 and 2.
4. Determine the mass of one of the small hangers that slide onto the meter stick. Let's call that hanger 1 and record that mass also in data table 1. Slide it somewhere on the meter stick it somewhere between the 60 cm mark and the 80 cm mark and lock it into position.
5. The hanging clamps can also be used to support the meter stick on the support stand. Arrange one the clamps to support the meter stick at the 0 cm end of the meter stick.
6. Determine the mass of a second hanger (hanger # 2) and record it's mass. Place it on the 100 cm end of the meter "upside down" so that you can hook the force sensor to it and raise that end of the meter stick with the force probe. Don't hook the force sensor up yet.
7. Hang a 100 gm mass from the clamp that you placed between the 60 and 80 cm mark
8. Zero the force sensors.
9. Hook one of the force sensors to the clamp at the 100 cm mark and, holding the body of the force sensor (not the wire) raise the end of the meter stick until the meter stick is horizontal. Your apparatus should

look like the sketch above while you are doing this.

10 Record the force probe reading in data table 1. You should think of the force sensor as measuring the upward force on the hanger attached to the 100 cm end of the meter stick.

11. Complete the rest of the entries in the data table assuming that the <u>axis of rotation is the support at the 0 cm mark.</u> You can assume the mass of the meter stick acts effectively at the midpoint of the meter stick (the center of mass).

Data Table 1

	Mass (kg)	Force (N)	Sign of Torque	Moment Arm (m)	Torque (N - m)
meter stick					
hanger 1					
hanger 2					
hanging mass					
force sensor					

Sum of the forces = __________ N

Sum of torques = __________ N-m

<u>Question 2:</u> The sum of the net torques IS zero even if the numerical result is not. Rather than simply explaining that the net torque is *close* to zero, justify that your net torque in small *within the context of this experiment*. Use data!!

Question 3: While the net torque is zero, the net force calculated from the forces in your data table is not zero. This is because the data table does not include the upward force supplied by the support at the 0 cm mark of the meter stick. Using the fact that in equilibrium that the net force is zero, calculate the magnitude of the support force (also frequently called a normal force).

Question 4: Explain why you did not need to know the value of the normal force in order to calculate the net torque for question 2?

Question 5: The net torque rule does not specify which axis to use for the torque calculation. This means that you can use any axis. Of course, for some choices the calculations are simpler than others.

Imagine that instead of calculating the torque about the 0 cm end of the meter stick, the calculation is done using an axis through the 50 cm mark on the meter stick. Remember, none of the force values have changed, just our axis for the torque calculation so you are not redoing the experiment or moving anything just calculating the torques about a different axis. Data Table 2 is provided to record your calculations for this exercise. The force values can just be copied from the Data Table 1

Data Table 2

	Mass (kg)	Force (N)	Sign of Torque	Moment Arm (m)	Torque (N - m)
Normal force					
hanger 1					
hanger 2					
hanging mass					
meter stick					
force sensor					

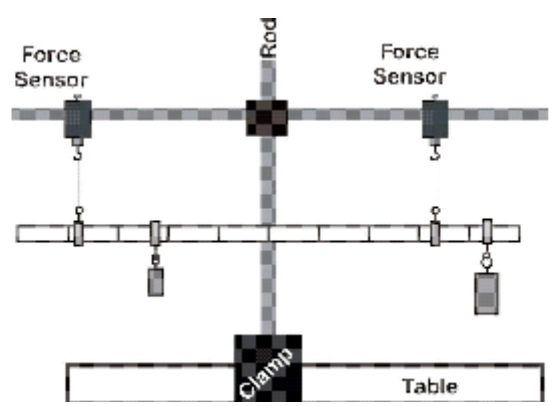
Sum of torques = ______________ N-m

<u>Question 6:</u> Again justify that the net torque is zero within the context of this experiment and your ability to measure.

<u>Part 3:</u>

For this part of the lab, you want to use the rods and clamps to set up an arrangement like the one shown in the sketch.

The arrangement is such that the lower horizontal rod is hanging free. The meter stick is not supported from below but only by the two force sensors. The picture also shows a string between the each force sensor and the hanger on the meter stick.



This is only in the sketch for clarity. You can connect the mass hanger directly on the force sensor as you did in part 2.

The position of the two hanging masses is up to you as are the values of the masses. Your only restriction is that they be different and that they be no less than 100 grams and no greater than 500 grams. The weight of the hangers is a part of your calculation and they do vary, so you will need to have measurements of all 4 hangers and record their positions along the meter stick (see Data Table 3)

The previous results should have convinced you that you can choose the axis of rotation for the torque calculation at any position that you like. For this part of the lab the choice will be yours

For the torque calculations below I will choose the axis of rotation to be:

____

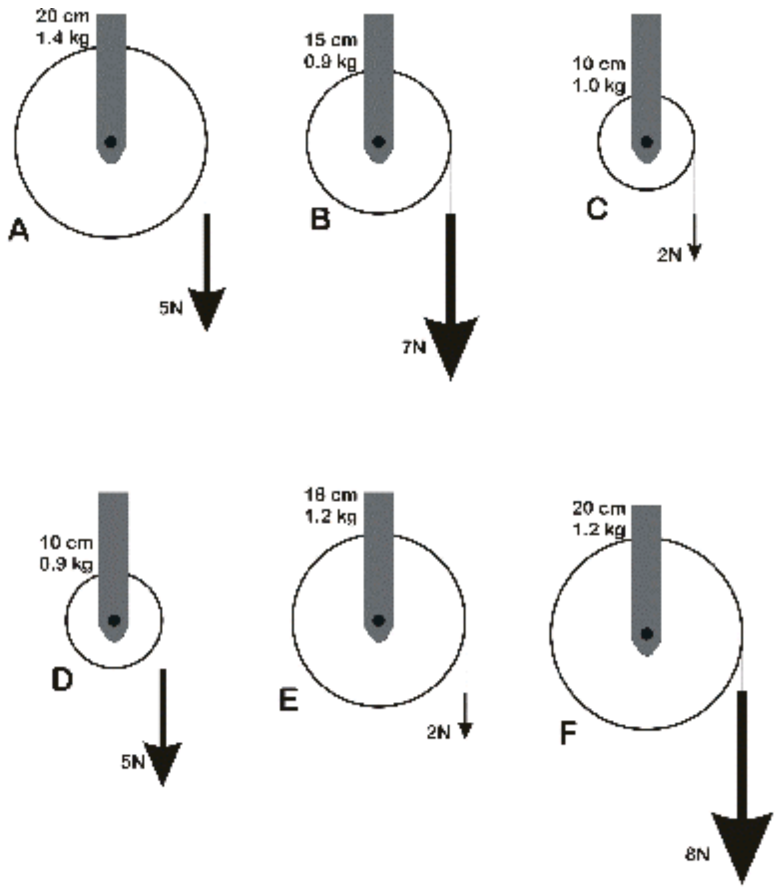
Data Table 3

	Mass (kg)	Force (N)	Position along meter stick (m)	Sign of Torque	Moment Arm (m)	Torque (N - m)
Hanger 1						
Hanger 2						
Hanger 3						
Hanger 4						
Hanging mass 1						
Hanging Mass 2						
Force Sensor 1						
Force Sensor 2						
Meter Stick						

<u>Question 6:</u> Did your net torque equal zero? Again . . . provide context.

<u>Question 7:</u> Why does it not make sense to calculate a percent difference between your measured net torque and the expected net torque?

Below are six similar situations. Each has a rotating disk with a string wrapped around it and mass suspended from the string. Rank each of these situation, from largest to smallest, based on the magnitude of the torque produced by the suspended mass.

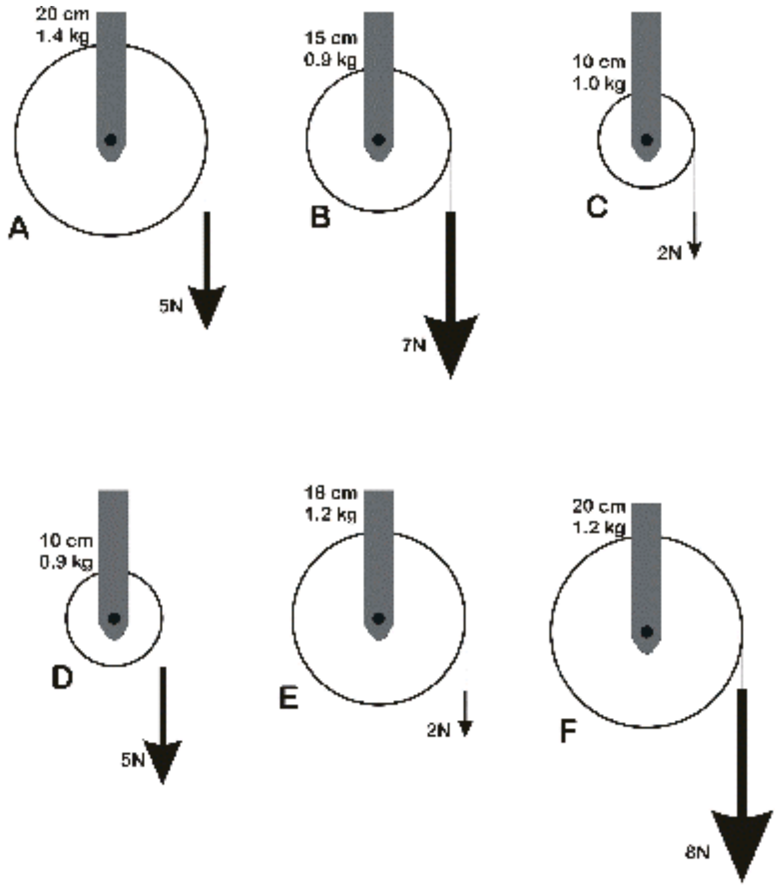


Largest ____ Smallest

☐ All the torques are zero

Explanation of rank:

Below are the same diagrams as on the previous page. Rank the situations, from largest to smallest, based on the angular acceleration of the rotating disks.



Largest _______________________________________ Smallest

☐ All the angular accelerations are zero

Explanation of rank: