

Lab  
10

Torque

What You Need To Know:

**Angular Systems** Every lab up to this point has dealt with objects moving in the linear system. In other words, objects moving in a straight line. Now we are going to deal with the angular system in which objects *rotate*. Every idea in the linear system will have an analogous idea in the angular system. For example, in the linear system we have velocity (which we now specify as *linear velocity*). Linear velocity tells you how far an object travels in a straight line every second (in units of ... m/s). In the angular system we have *angular velocity* which tells you how many times an object rotates every second (in units of ... revolutions/s). There are many other concepts we could discuss but today’s lab is just going to focus on one of these and that is *torque*.

**Force and Newton’s 2<sup>nd</sup> Law** Before we get to torque, let’s jump back a bit and review some ideas in the linear system. You should know by now that a *force* is a push or a pull on an object. More specifically, if you apply a *single* force, *F*, to an object it will move *in a straight line*. See **Figure 1a**. According to Newton’s 2<sup>nd</sup> Law, ( $\Sigma F = ma$ , *net force* equals *mass times acceleration*) the object *has* to accelerate. This is so because if there is *only one* force acting on an object then there *must* be a net force and therefore an acceleration.

If there are *two* forces acting on an object then the object might or might not accelerate. If the two forces are *equal* but pointing in *opposite directions* then they cancel out and the *net force is zero* and the object will *not* accelerate. See **Figure 1b**.

**Torque** Now let’s look at the same ideas but in the angular system. The analogous idea of force in the angular system is called *torque*. A torque is a “force” that makes an object want to *rotate*. Think of it as a rotational force. The equation for torque is written as ...

$$\tau = Fr \quad \left| \begin{array}{l} \tau \text{ is the torque on an object (in Newton-meters, N}\cdot\text{m)} \\ F \text{ is the force acting on an object (in Newtons, N)} \\ r \text{ is a perpendicular distance [explained below] (in meters, m)} \end{array} \right.$$

Many people think that, *r*, stands for “radius” but that is not always the case. This can lead to much confusion on torques. It is much better to think of, *r*, as the distance from a chosen reference point to the point at which the force, *F*, is acting. (That’s how it’s defined anyway.) Let’s say you have a pulley with a rope wrapped around it. You pull on the rope which gives the rope a tension, *T*. See **Figure 2**. In this case the chosen reference point is the center of the pulley. It was chosen there because that is the point at which the pulley is rotating. (More on this later.) Notice how the distance, *r*, is shown; from the reference point to where the tension is acting. (And yes, in this case that distance *does* turn out to be the radius of the pulley.)

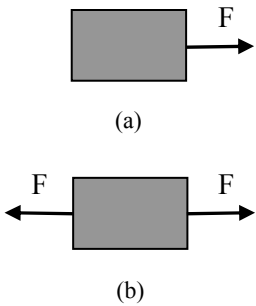


FIGURE 1 – Forces acting on an object

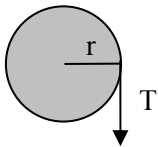


FIGURE 2 – Rope acting on a pulley

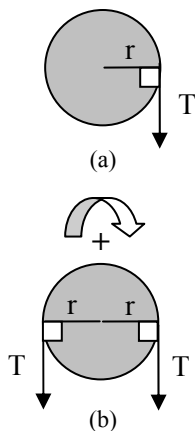


FIGURE 3 –  
Torques  
acting on an  
object

Another thing you have to remember is that when you plug in for  $F$  and  $r$  they have to be perpendicular to each other. See **Figure 3a**. If they are not perpendicular then you have to either find a component of  $F$  that is perpendicular to  $r$  or vice versa. In this lab we will only deal with  $F$ 's and  $r$ 's that are already perpendicular. So, this idea will be left up to your instructor in your lecture to delve into.

**Net Torque** The equation for Newton's 2<sup>nd</sup> Law in the angular system is very similar in form to the one for the linear system.

$$\Sigma\tau = I\alpha$$

$\Sigma\tau$  is the net torque on an object (in Newton-meters, N·m)  
 $I$  is the moment of inertia on an object (in kg·m<sup>2</sup>)  
 $\alpha$  is angular acceleration of an object (in radians/s<sup>2</sup>)

All of the variables are analogous to each other; force and torque, mass and moment of inertia, and linear acceleration and angular acceleration. You simply switch out one for the other.

The ideas work out the same as well. In **Figure 3a** there is one torque acting on the system (in this case,  $\tau = Tr$ ). If you apply a *single* torque to an object it will *rotate*, and according to Newton's 2<sup>nd</sup> Law for the angular system, the object *has* to *angularly* accelerate. This is so because if there is *only one* torque acting on an object then there *must* be a net torque and therefore an angular acceleration. This is the same idea discussed for the linear system on the previous page.

If there are *two* torques acting on an object then the object might or might not angularly accelerate. If the two torques are *equal* but pointing in *opposite directions* then they cancel out and the *net torque is zero* and the object will *not* accelerate. See **Figure 3b**. (Again, same idea as before.)

Just like in the linear system in which we have to choose a linear direction as positive, we also have to choose a rotational direction as positive. That will be either clockwise or counterclockwise. In **Figure 3b** let's call clockwise positive (as shown). Now we can say that the tension in the rope on the right is causing a torque in the clockwise direction (positive) and therefore trying to make the pulley rotate that way. The tension in the rope on the left is causing a torque in the counterclockwise direction (negative) and therefore trying to make the pulley rotate that way. These two torques cancel each other out and the pulley does not rotate at all.

**Center Of Mass** In the past, when drawing free-body diagrams, you probably have been just arbitrarily drawing in a weight vector at any particular location. In dealing with torque we can see that the location of the force is important. So, now you have to be more careful in which place you draw your weight vector. You should be drawing it at the *center of mass* of your object.

The center of mass of an object is defined as the average location of the total mass of the object. *Huh?* Ok ... if you took the entire mass of your object and compressed it down to a *single point* your object would still act as though the mass were spread out before you compressed it. That point is the center of mass. *Double huh?* Let's discuss an example ...

Let's say we have a meter stick. Its mass is uniformly distributed throughout itself so we would say that its center of mass is at the exact center of the meter stick. This is where we would place the weight vector of the object. **See Figure 4a.** Now, let's say that we drill a hole on the right end of the meter stick. The mass of the stick is no longer distributed uniformly across the stick because of the hole. This would cause the center of mass of the stick to be shifted to the left. **See Figure 4b.**



FIGURE 4 – Centers of Mass for meter sticks

In today's lab you will be dealing with a meter stick whose mass is not uniformly distributed. They have been altered specifically for this lab. So, one of the first things that you will have to do is find the center of mass of the meter stick.

**The Equipment** The most basic part of the lab is the fulcrum and meter stick. **See Figure 5.** The fulcrum is mounted to a block of wood and is used as a pivot point for the meter stick. There are also three clamps on your table. Two of them have swinging hangers on them, one doesn't. **See Figure 6.** You can attach clamps to the meter stick to either hold the meter stick up at the pivot point on the fulcrum or you can use them to hang extra masses. **See Figure 5.**

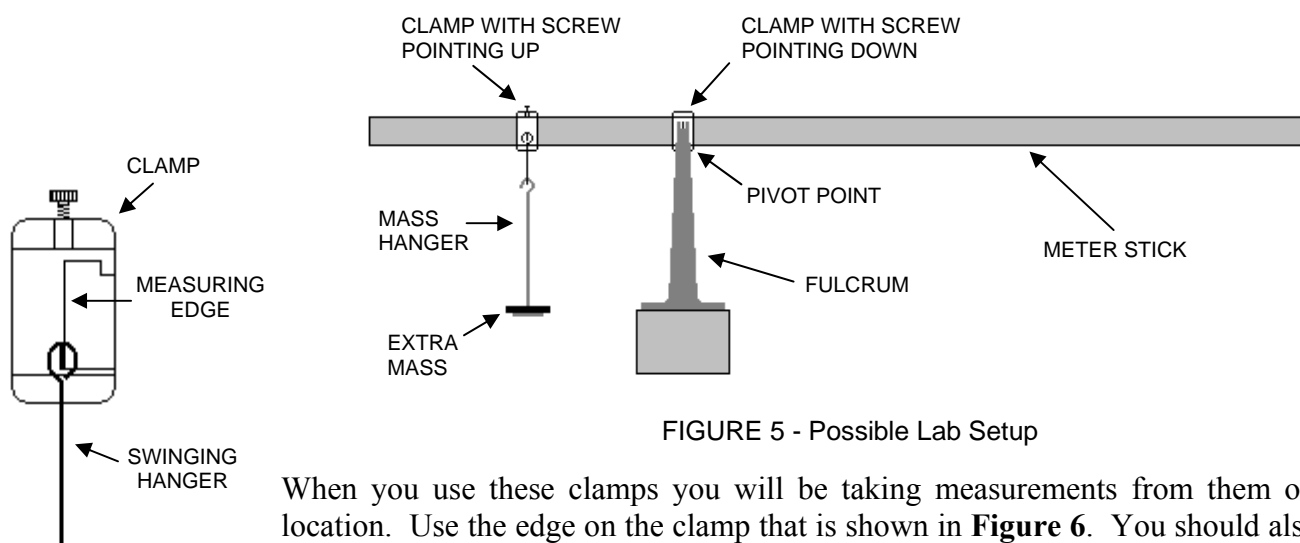


FIGURE 5 - Possible Lab Setup

When you use these clamps you will be taking measurements from them on their location. Use the edge on the clamp that is shown in **Figure 6.** You should also have two mass hangers as well as a set of masses that you set on the platform of the hanger. **See Figure 5.**

FIGURE 6 -  
Clamp

### What You Need To Do:

**Part 1 - Center Of Mass** In order to find all the torques on an object, you have to include the torque due to the weight of the object. Depending on the reference point that you choose, the weight of the object might have a torque. The location at which

the weight of the object acts is at the center of mass of the object. So, the first thing we are going to do is find the center of mass of the meter stick.

NOTE: On the last page of the lab there is a chart that you can use to fill in your data. Detach it and use it as the first page of your lab report. You can answer questions on this sheet too. Use your own loose leaf paper if you need more room for answers and calculations.

**A)** Slide the clamp without the swinging hanger onto the meter stick until it gets to about the center of the stick. NOTE: Make sure the screw on the clamp is pointing *down* and that the *metric side* is facing you.

**B)** Place the meter stick on the fulcrum with the clamp right at the pivot point. See **Figure 5**. Adjust the location of the clamp back and forth until the stick remains relatively horizontal.

**C)** Once the stick is balanced, record the location of the clamp. This is the location of the center of mass of the meter stick. You will be using the value throughout the lab.

Notice that, before the clamp was at the center of mass, the stick rotated about the fulcrum. That means that there must have been a net torque on the stick. The weight of the stick was acting at a distance,  $r$ , away from the fulcrum and thus was causing a net torque (i.e. the stick rotated). Once you placed the clamp right at the center of mass, the weight of the stick was acting *at the fulcrum*. That means that  $r = 0$  and there would not be a torque (i.e. the stick remained horizontal).

**Part 2 - Single Torque** Leave the clamp at the center of mass of the stick and keep this setup on the fulcrum.

**A)** While holding the meter stick horizontal, slide a clamp with a swinging hanger to about the 80 cm mark.

**B)** Release the meter stick. Describe what happens and also explain why in terms of what has been discussed so far.

**C)** While holding the meter stick horizontal, remove the clamp at 80 cm and place it on the other side of the stick at 20 cm.

**D)** Release the meter stick. Describe what happens and also explain why in terms of what has been discussed so far.

For each of the instances above, in adding the clamp to one side of the stick we added a net torque to the system. This caused the stick to rotate. One way caused a clockwise torque, the other way caused a counterclockwise torque.

**Part 3 - Net Torque** So far there has only been one torque acting on the ruler. Now you will be dealing with a system that has multiple torques acting on it.

**A)** Using the digital scales in the back of the lab, find the mass of each hanger assembly *which includes* the clamp, the swinging hanger, and the mass hanger. **See Figure 5 & 6.** Do not assume that each assembly has the same overall mass. Find both separately.

**B)** While the meter stick is balanced at its center of mass, place one hanger assembly at 20 cm on the stick. **NOTE:** Have the screw on the clamp pointing *upwards* for any clamp with a swinging hanger. It's easier to adjust that way. **See Figure 5.**

**C)** Holding the meter stick horizontal, take the other hanger assembly and slide it on the stick from the right hand side until the stick remains horizontal when you let it go.

**Question 1** How many forces are acting on the meter stick? Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well.

**Question 2** If the location of the fulcrum is taken as the reference point (this will be the case for the entire lab), how many torques are acting on the meter stick? Why is this number different than the number you wrote for the answer to **Question 1**?

**Question 3** In what directions are the torques acting (Counterclockwise or Clockwise)?

**Question 4** What is the net torque acting on the meter stick? How do you know this by looking at the meter stick?

**D)** Calculate the *weight* of each hanger assembly. (Make sure you are using units of kilograms for *mass*.) Put these values in the chart in the row labeled **Part 3**, under the columns labeled as ***F***. **NOTE:** In the chart there are extra columns for torques that you might not use depending on which part of the lab you are working. This is left ambiguous in order for YOU to determine how many torques you have, either clockwise or counterclockwise.

**E)** Measure the distance, ***r***, (in meters) for each torque. Remember, ***r*** is defined as the distance from your chosen reference point (in this case, the fulcrum) out to where your force is acting. Place these values in the chart.

**F)** Calculate the torques,  **$\tau$** , and put these values in the chart. Also, put these values in for the total torques since there is only one torque per side. Calculate a percent difference between these totals. If you got a value greater than 5% then you are doing something wrong. Go back and check your data.

**Part 4 - C of M as Torque** For this section you will be moving the fulcrum away from the center of mass. This will cause the weight of the meter stick to have a torque.

**A)** Go to the back of the lab room and measure the mass of the meter stick **WITHOUT** the fulcrum clamp on it. Reattach the clamp and place it at 60 cm.

**B)** Put the meter stick back on the fulcrum. Add an extra mass of 100 g to a hanger assembly. Place this hanger assembly at a point on the meter stick so that the meter stick is balanced.

**Question 5** How did you know where to place the hanger to balance the stick? Explain in detail using torques.

**C)** Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well. Describe the torques acting on the stick.

**D)** Calculate the weights that are causing the torques on the stick and place these values in the appropriate places in the row labeled **Part 4**. Make sure you now include the 100 g mass for the hanger assembly.

**E)** Measure the distance,  $r$ , for each torque. Place these values in the chart.

**F)** Calculate your torques and total torque. Calculate a percent difference between your total torque values. If you got a value greater than 5% then you are doing something wrong. Go back and check your data.

**Part 5 - Multiple Torques on a Side** Remove the hanger assembly currently on the meter stick. Keep the fulcrum at 60 cm.

**A)** Add an extra mass of 200 g to one of the hanger assemblies and place it at 90 cm.

**B)** Add an extra mass of 100 g to the other hanger assembly and place it on the meter stick to balance the system.

**C)** Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well. Describe the torques acting on the stick.

**D)** Calculate the weights for each torque acting on the stick and place these values in the appropriate places in the row labeled **Part 5**.

**E)** Measure the distance,  $r$ , for each torque. Place these values in the chart.

**F)** Calculate your torques and total torque. Calculate a percent difference between your total torque values. If you got a value greater than 5% then you are doing something wrong. Go back and check your data.

**Part 6 - Mixin' It Up** Remove all hanger assemblies.

**A)** Place the fulcrum at 75 cm.

**B)** Take one hanger assembly and place it at 84 cm.

**C)** Take the other hanger assembly and add 20 g to it.

**D)** By either adding mass (NOTE: add *no more* than 150 g) to the first hanger assembly AND/OR adjusting the location of the second hanger assembly, balance the system. (You can place the second hanger anywhere on the meter stick.)

**E)** Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well. Describe the torques acting on the stick.

**F)** Appropriately fill out the row labeled **Part 6** in your chart as you have been.

**Part 7 – Calculating Tension** So far the only torques you've been dealing with have been caused by weights. Now, a tension is going to cause a torque.

**A)** Open the file **FORCE PROBE**. Push the CONNECT button on the extra window that opens. With nothing hanging from the force sensor, push the button to the left of the COLLECT button to zero the sensor.

**B)** Place the fulcrum at 20 cm.

**C)** On the table there is a piece of string with one end tied in a big loop and the other in a small loop. Slide the big loop around the ruler until it is at 70 cm. Have the small loop hang on the hook on the Force Sensor which is hanging from a stand. Adjust the height of the Force Sensor until the meter stick is horizontal. See **Figure 8**.

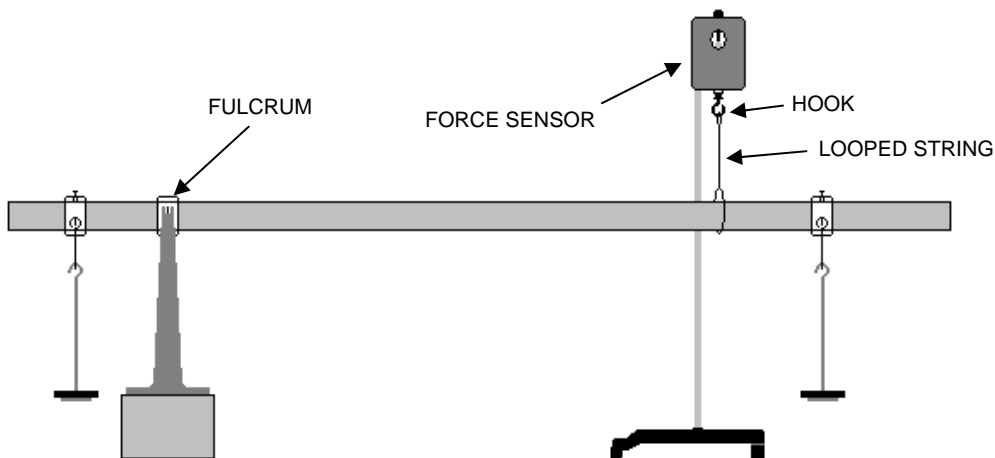


FIGURE 8 - Lab Setup for Tension

**D)** Take one hanger assembly and place it at 8 cm. Put an extra mass of 150 g on the mass hanger.

**E)** Take the other hanger assembly and place it at 83 cm. Put an extra mass of 100 g on the mass hanger.

**F)** Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well. Describe the torques acting on the stick.

- G)** So far you have been verifying that the clockwise torques equal the counterclockwise torques. Based on this idea, make an equation that will allow you to calculate the tension in the string. Make sure you use units of kilograms and meters so that you will get Newtons for tension. Calculate the tension.
- H)** On the screen there will be a small window that tells you the tension in the string. Record this value.
- I)** Calculate a percent difference between the computer value and your calculated value. If you got a value greater than 10% then you are doing something wrong. Go back and check your data and calculations.
- J)** Remove all clamps from the meter stick. Thanks!

### **What You Need To Turn In:**

Write your lab report using the next page as the front sheet. Use your own paper for additional pages. Make sure you show your work for each section in the corresponding section in your report. Answer all of the questions.



