Physics 250 Laboratory: Torque

Date____________________ Names ____

Section__________________ ____

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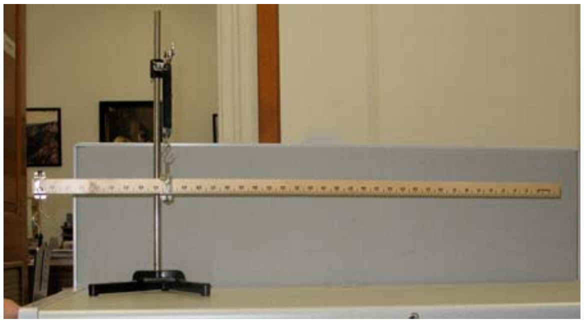
Objectives

To analyze the relationship between forces and torques and their role in systems in equilibrium. To analyze the role of forces & torque in levers, the human arm, and wheel & axle systems.

Equipment

- spring scales (2-500 g scales or a 250 g & 500 g scale)
- wheel & axle system [variable step pulley] clamped to table
- thread or string (2 pieces)
- masses (for hangers)
- mass hangers (4)
- meter stick
- fulcrum stand
- mass hanger clips for meter stick (5)



Activity 1: Levers

Levers are rigid bars that can rotate about a fixed point called a fulcrum. With a little knowledge of physics and reasoning with ratios, you could utilize a lever to lift or hoist objects much heavier than you could lift with your bare hands. Consider Figure 1 shown below. As a simplified model for the things you can do with a lever, we'll consider a meter stick able to rotate about a fulcrum. We've labeled one of the forces $\vec{F}_a$, the applied force. This is the force that you (or some other agent) might apply to lift the weight W.

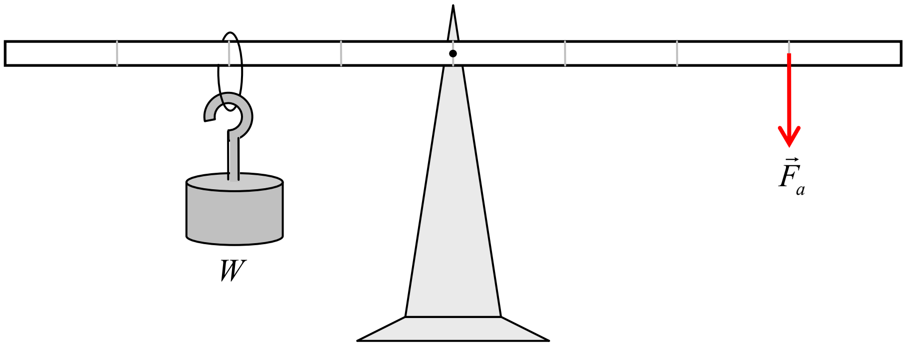
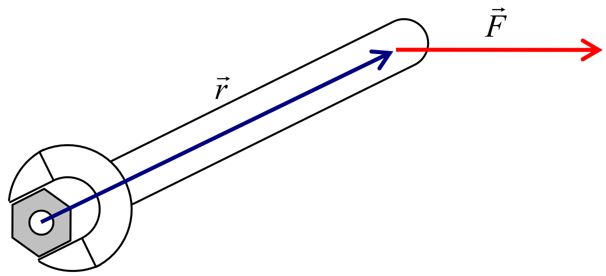
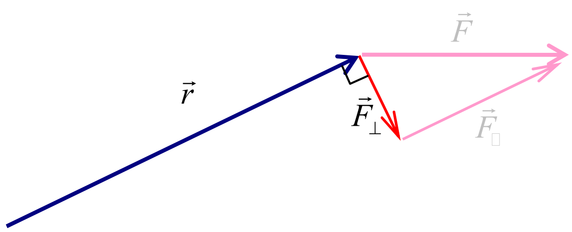


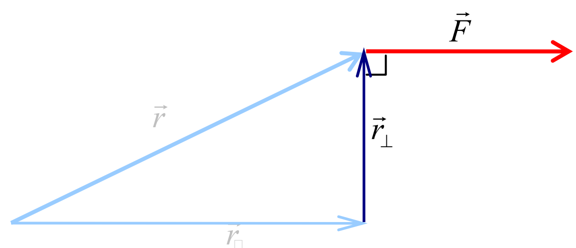
Figure 1

We would say that the weight to be lifted tends to cause the lever to rotate in one direction (in this case counter-clockwise) and the applied force tends to rotate it in the opposite direction (clockwise). In order to lift the weight, your "turning effect" must initially exceed the "turning effect" of the weight. The term that we use to quantify this turning effect is **torque**, which we conventionally symbolize with the Greek letter τ (tau). We would naturally expect that the distance from the pivot point to where the force is applied and the magnitude of the force that's applied both matter when it comes to determining torque. Experimentally, though, we find that it's not the whole force, but only the *component* of the force that's *perpendicular* to the object being turned actually gives any contribution to the torque.

There are actually two equivalent ways to view this. One, as described above, is to state that the torque depends upon the actual distance between the pivot and the point of application of the force **and** on the perpendicular component of the force. The other way to view this is to say that the torque depends upon the magnitude of the force that's applied and the component of the distance between the pivot and the application point that's perpendicular to the force. In the second case, we refer to this projection of the distance perpendicular to the force as the "lever arm".







So, we can either measure the component of the force perpendicular to the distance and multiply it by the distance, or measure the component of the distance perpendicular to the force (the lever arm) and multiply it by the force. Both will give you the same value for the magnitude of the torque:

$$\tau = rF_\perp = r_\perp F$$

Procedure

In this experiment, you will use two hanging masses to simulate the weight to be lifted and the force applied by you, and you will compare the clockwise and counter-clockwise torques about the fulcrum.

1.) First, with nothing hanging from the meter stick at all, make sure that the meter stick balances by itself.

    We would expect that for an object made of the same uniform material throughout, the center of mass should be right at the geometric center of the object. For objects not made of a uniform-density material, the center of mass can be found by subtly adjusting the support point until the object is balanced on that support point. The center of mass is then somewhere directly above (or below) the support point.

2.) Once the meter stick is balanced on its own, we can begin. First, we want to know the mass of the clip that we will use for hanging masses. We could just weight one, but that wouldn't be any fun. Instead, we're going to use torque to find the mass of the clips. On the far left side of the stick, just place the clip with no masses hanging on it. Hang a 50g mass hanger from another mass hanger clip on the right side of the stick. Adjust the position of the mass on the right hand side until the stick balances. Record the distance ***from the fulcrum*** for the masses on both sides (clip on the left side, clip and hanging mass on the right side), and the mass added to the clip on the right hand side in the table below.

m_{hang} (kg)	d_{hang} (m)	d_{clip} (m)	m_{clip} (kg) [calculated]	m_{clip} (kg) [from scale]

The counter-clockwise torque acting on the bar will be due to the weight of a clip and the clockwise torque will be due to the weight of a clip and the mass hanging from it. For them to balance, the counter-clockwise and clockwise torques must balance, or

$$m_{clip}\, d_{clip}\, g = (m_{clip} + m_{hang})\, d_{hang}\, g$$

Using algebra, solve for m_{clip} in terms of m_{hang}, d_{hang}, and d_{clip}. Show your solution and work below. Then enter your value for m_{clip} in the table above. Now use the scale to measure the mass of the clip and see how close you got!

3.) Now hang a mass from a mass hanger on the left side of the stick. (Recall that this is our model representation of the weight we're trying to lift with our lever.) Record its distance ***from the fulcrum*** and the total mass of the clip plus hanging mass in the table below.

4.) Now, hang a different mass on the right side of the fulcrum. (Recall that this is our representation in our model of the force we'd need to apply down on the lever.) Adjust the location of the hanger until the system achieves balance again. Record the distance of this mass ***from the fulcrum*** and the total mass of clip plus hanging mass on this side.

5.) For a different pair of masses, repeat steps three and four above and record your values in the table below.

6.) Compute the torques exerted in each case, and compare them by computing the percent difference between your "applied" torque on the right and the torque of the weight on the left. **Show your calculations in the space provided below the table.**

Trial	m_L (kg)	r_L (m)	m_R (kg)	r_R (m)	$\tau_{\text{counter-clockwise}}$ (N·m)	$\tau_{\text{clockwise}}$ (N·m)	% diff (*)
1							
2							

(*) Note: % diff = 100% • (difference in torques) / (average torque)

Discuss possible sources of error in your experiment. (Be specific and avoid vague and meaningless phrases such as "human error".)

In each trial, how could we determine the magnitude of the force exerted by the fulcrum?

Activity 2. Balancing three and four masses

Let's apply this same idea but now with three and four masses hanging on the stick. Enter your values for the masses and distances to the pivot below. Calculate the total torques on each side and the % difference. Use the space provided below the table to show your calculations.

Trial	m_L (kg)	r_L (m)	m_R (kg)	r_R (m)	$\tau_{\text{counter-clockwise}}$ (N·m)	$\tau_{\text{clockwise}}$ (N·m)	% diff
Three masses	________ ________	________ ________	________ ________	________ ________			
Four masses	________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________			

Activity 3. Torque in the Arm

In this part of the lab, we will use the stick as an artificial forearm. We will use two spring scales: one for the biceps muscle and one for the elbow joint.

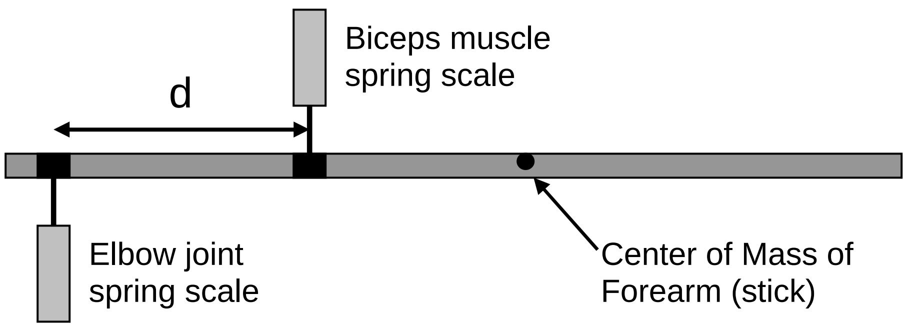
1) First, we'll want to record the position of the center of mass of the meter stick:

Center of mass position _____________________ m

3) Second, we want to know the weight of the stick. Remove all the clips and weigh the stick on the balance. Record your value for the mass and weight below.

Mass of stick ___________ kg Weight of stick ________________________ N

2) Put on a mass hanger clip approximately a quarter of the length of the stick from the left edge (e.g., 25-30 cm). Then place a second clip on the stick very near the left edge (e.g., 5 cm). Hang a 500 g (5 N) spring scale from the support stand and hang the stick (from the clip at 25-30 cm) from this spring scale. Then hang the stick from the spring scales as shown below. (See photo on first page.) The stick will not be secured to anything so be careful.



Record the distance between the elbow joint spring scale and the center of mass for the forearm (stick):

_____________________ m

3) Hold the stick in place by pulling straight up with the right (biceps muscle) spring scale and down with the left (elbow joint) spring scale. Vary the distance d by varying the biceps spring scale from the 25-30 cm position to the smallest d value possible before the spring scales exceed their maximum values. Keep the elbow joint fixed. Of course, the biceps muscle is not attached halfway out on the arm, but we are experimenting to see what the effect of varying where the muscle is attached would be. *Be sure that the spring scales are pulling vertically (just to simplify our analysis so we don't have to include angles in our calculations). Be sure when using the spring scales that they are oriented so that the can slide freely. Make sure the support is as high as possible so you have the most room to work beneath it; for this part of the lab, position the support near the edge of the table (just be careful).* For the smallest values of d, you may need someone to hold the biceps muscle spring scale instead of hanging it from the support.

	Distance (d) between muscle and elbow (m)	Elbow Joint Force (N)	Muscle Force (N)
1			
2			
3			
4			

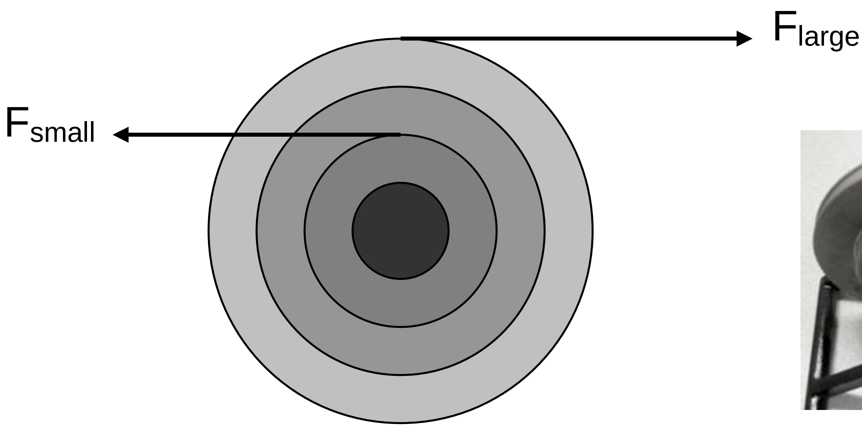
Use the distances and forces you measured for the four different positions of the "biceps muscle" to calculate the total counter-clockwise and clockwise torques and the total upwards and downwards force on the stick. Put the results of your calculations in the table below. *For calculating torque, use the joint as your pivot point.* **To help you in doing these calculations, draw an extended free-body diagram for the stick below**. (Don't forget the weight of the clips!)

	d (m)	CCW Torque about elbow (Nm)	CW Torque about elbow (Nm)	% Diff in Torque	Upwards Force (N)	Downwards Force (N)	% Diff in Force
1							
2							
3							
4							

What value of d most closely approximates the real position of the biceps muscle? (Would it be a larger or smaller value for d?) What can you deduce about the forces exerted by the biceps muscle and elbow joint just to hold your arm level? How do they compare to the weight of the forearm?

Activity 4. Wheel & Axle

A wheel & axle system is used in many machines – either to change the force required to accomplish a task or to change the speed in a system. A wheel & axle system is simply two discs on the same axis and connected so that they always spin together (i.e., with the same angular velocity ω). Traditionally the "axle" is just the smaller of the two discs and the "wheel" is the larger disc. Wrap a string a few times around the largest of the wheels on the wheel & axle system on your lab table. (It should look like 4 wheels of different sizes connected together.) Then wrap a string ***the other direction*** around the second smallest wheel. Your setup should like something like what is pictured below:



You will be attaching a spring scale to each of these strings and then playing a bit of tug-of-war. That is, you will pull on one string and then see how hard you need to pull on the other string for the system to be in equilibrium (i.e., not start rotating). *From your understanding of torque, do you think the two forces will be the same or will they be different? (And if different, which one will be bigger?) Explain your reasoning below before continuing.*

Now give it a try: F_{small} = ____________________N , F_{large} = _____________________ N

Calculate the torques and compare:

τ_{small} = _________________________ Nm, τ_{large} = __________________________ Nm

If you wanted to lift something heavy using this device, would you have the heavy object connected to the larger disc and then pull one the smaller disc, or vice-versa? Why? What would be the effect of using this device on the speed that the object lifts? That is, if you pulled your string at a speed of 10 cm/s, would the object lift 10 cm/s, or would it lift faster or slower?