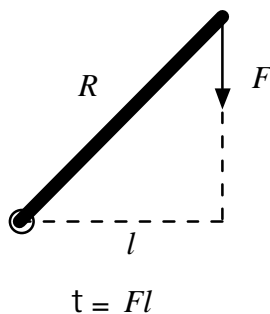


Rotational Equilibrium

Introduction:

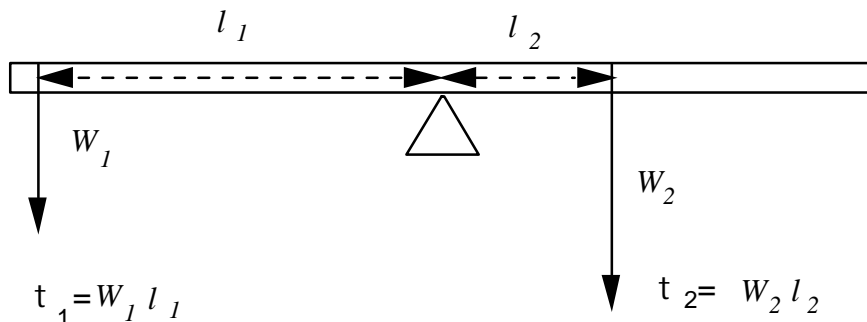
In the past experiments, we have observed several cases of equilibrium, that is, the state for which there is no net force on an object. We noted that in this case, the linear acceleration of the object was zero. All of the experiments have dealt with forces which caused the objects involved to move in a straight line. In the real world objects are not simply masses at a point but, rather, they have finite volumes with a total mass and a center of gravity. Not only can these objects move in a straight line, but they can rotate around a fixed axis similar to the way in which the Earth rotates on its axis. The speed at which an object rotates (in radians per second) is called the angular velocity (ω) and the rate of change of the angular velocity is called the angular acceleration (α). Whereas a force is responsible for imparting a linear acceleration, another quantity called **torque** (τ) is responsible for angular acceleration. The torque is defined as the product of the force and its lever arm. The **lever arm** is defined as the distance (l) perpendicular to the force between the force and the axis of rotation. The diagram below illustrates the torque exerted on a rod of length R about a pivot point on one end.



The two cases drawn above have the same torque. The drawing on the right shows how to find the lever arm when the force is not perpendicular to the rod. The case in the diagram is similar to the use of a wrench in tightening a bolt. If the force were in the same direction as the wrench, the bolt would never turn. If the force was perpendicular to the wrench, then l would equal R and the torque would be greater than in the diagram.

Rotational equilibrium is defined as the state of a system for which the total angular acceleration is zero. Since it is the torque which is responsible for this acceleration, a total torque of zero is also required for a system to be in rotational equilibrium.

The objective of this experiment is to consider the effects of various torques on a meter stick. You will place the meter stick on a fulcrum, which is placed at the center of gravity of the meter stick. You will then add different weights on either side of the fulcrum at different distances until the meter stick is balanced and level. At this point we will have achieved static rotational equilibrium, and all the clockwise (cw) torques (those which tend to rotate it clockwise) and the counter-clockwise (ccw) torques will be in balance.



After this, we will place the fulcrum at some point away from the center of the meter stick and repeat the process. Since all of the mass is effectively concentrated at the center of gravity, one must account for the torque resulting from gravity acting on the meter stick. Balancing the meter stick in this manner will make it possible to determine its weight.

Procedure:

Part One

1. Place the fulcrum knife-edge on the meter stick and clamp it at the 50 cm mark. Place the fulcrum base on the corner of your table diagonally so that both ends clear the table. Check to see if the meter stick alone will balance in a level position. If not, make small adjustments to the position of the fulcrum knife-edge until a level balance is achieved. Record the position of the knife-edge when a balance is achieved as the position of the center of mass of the meter stick.
2. Place a weight hanger on each side of the fulcrum and add a weight hook to each. From the slot masses available, add about 200-250 g to one hook and 300-400 g to the other. Manipulate the position of both hangers until a level balanced equilibrium is achieved.

3. Record the clockwise and counter-clockwise lever arms by measuring the distance between the knife-edge and weight-hooks (noting whether they are on the right or left of the knife-edge). Record the total mass hanging at each position. The total mass is the combined mass of the weight hanger, the weight hook and the added weights. It may be necessary to use the triple beam balance to find this. Mark each hanger/hook with L or R to indicate whether it is on the left or the right.

Part Two

4. Place the knife-edge about 20-30 cm from the end of the meter stick and place a single weight hanger and weight hook on the short end of the stick. Place slot masses on this hook until a level balanced equilibrium is achieved.

5. The balance can be refined by moving the knife-edge and changing the amount of weight on the hook.

6. Record l_{cw} and l_{ccw} by measuring the distance between the fulcrum knife-edge and the weight hanger and the distance between the knife-edge and the recorded position of the center of mass. Record the total amount of mass needed to balance the weight of the meter stick.

7. Record the mass of the meter stick as measured with a triple beam balance. Record this below the table, in order to compare it to the value determined from the torques.

Part Three

8. Without moving the knife edge, add a small weight to the end of the meter stick on the long end. Balance this by adjusting the amount of weight and the short end until a balance is achieved. There are now three torques on the system. Draw a picture of the meter stick, measure and label the various weights and lever arms and calculate the torques.

Calculations:

Calculate all weights in units of Newtons.

Using the data in Part 1, calculate the counter-clockwise and clockwise torques involved. Are they near equal? Consider the number of significant figures.

Using the data in Part 2, calculate the torque from the hanging weight. Assume the torque from the hanging weight is the equal and opposite to the torque created by the center of mass. Use these data to calculate the mass of the meter stick. Compare this

with the value you measured on the triple-beam balance.

Using your solution for Part Two, calculate the torques for Part Three. Find their sum, remembering that you subtract torques in opposite directions and add those in similar directions.

Conclusions:

Part One

1. Are the torques roughly equal? What does this tell you about the condition for equilibrium?
2. To how many significant figures are the torques similar? What other values were measured to this degree of precision?

Part Two

3. How does the calculated mass compare to the mass of the meter stick found on the triple beam balance?

Part Three

4. How did the set of three torques balance out?

Error Analysis:

Describe sources of error for this experiment.

Rotational Equilibrium

Name: _____

Abstract:

Part One:

	mass	weight	l	τ
clockwise				
counter-clockwise				

total torque:

Calculations:

Part Two:

Read Carefully: In this part, one weight and both lever arms are measured. Assume the torques (cw, ccw) to be equal. You are to calculate the second weight, which is the weight of the meter stick. Label which weight is that of the meter stick.

	mass	weight	l	τ
clockwise				
counter-clockwise				

Part Three:

Label the meter stick below with the appropriate weights and lever arms for part three and compute the individual and total torques. (Be sure to write in your numerical values with appropriate units.)



Calculations:

Conclusions:

Error Analysis:

