Torques

Introduction
During this lab you will become more familiar with the concepts of torque. The purpose of this lab is to determine if the rotational equilibrium condition, $\Sigma\tau = 0$, holds experimentally.

Equipment

Meter stick (1) - no metal ends	Weight Hanger (1)
Fulcrum (1)	Mass Set (1)
Clamps (4)	Digital Scale (1)

Theory
For a body to be in static equilibrium, two conditions have to be met:

$$\Sigma F = 0 \quad \text{and} \quad \Sigma\tau = 0$$

where F is force and τ is torque. (The torque is the force times the lever arm, r)

The first condition, $\Sigma F = 0$, is concerned with translational equilibrium and ensures that the object is at rest or is moving at a uniform linear velocity.

The second condition, $\Sigma\tau = 0$, is concerned with rotational equilibrium and ensures that the object is not rotating or is rotating at a uniform angular velocity.

Special Instructions
Goals - One of the primary goals of this lab is accurate measurement with attention to detail and the use of the correct number of significant figures. I know that you can finish this lab quickly – but don't. Squeeze as much precision as you can out of this set of equipment. Think up ways of avoiding errors and inaccuracies rather than explaining them away in the lab report.
Units - In this lab you will find it convenient to use grams as the mass unit and centimeters as the distance measure. The nature of the torque balance equations allows us to take this short cut for convenience during this lab.

Equipment Procedures
Fulcrum Placement - Raise the fulcrum with a Lab Jack or by a textbook placed under it if the weight hangers are too long and touch the top surface of the lab table.

Gram Weights - In the four (4) cases below the mass numbers called for are the amounts of mass to be placed on the weight hangers. When performing the calculations of the torque you will need to use the Total Mass for each. The TOTAL is the mass of the Clamp, the mass of the Weight Hanger and the added mass.

Meter Stick Set Up - Measure the mass of a meter stick alone, without any clamps on it. Remove the “V-shaped” wire from the clamp that will serve as the meter stick balance pivot. Place the clamp on the meter stick with the tightening screw pointing down - do not tighten the screw yet. This orientation of the tightening screw is necessary to place the center of mass below the pivot point so that a stable equilibrium position exists for the meter stick. Place the meter stick on a fulcrum support stand.

Meter Stick Balance - Slide the meter stick through the clamp to the middle of the meter stick (50.0 cm) and place it on the fulcrum. Adjust the relative position of the meter stick in the clamp until the stick is balanced on the fulcrum stand. This balancing point is called the center of mass of the meter stick and it should be at 50.0 cm plus or minus a few mm. Record this value, read off the meter stick scale, as the meter stick center of mass x_0 in the Data Table.

Experimental Procedures

(For each setup, draw a scale diagram of the setup)

Case 1. With the meter stick on the support stand, suspend a mass m_1 = 100g at the 15-cm mark on the meter stick. Then adjust the lever arm for a mass m_2 = 200 g at the other end of the meter stick.

Record the masses and the x-position as read on the meter stick and then calculate and record the lever arms. Compute the torques and find a percent difference between the clockwise (τ_{cw}) torques and counterclockwise (τ_{cc}) torques. Record the % Difference value on your Data Sheet.

Case 2. Place m_1 = 100 g at the 20-cm mark and m_2 = 200 g is at the 60-cm mark on the meter stick. Experimentally determine the position for m_3 = 50 g so that the system is in equilibrium. Follow a procedure similar to steps 2 and 3. Compute the percent difference between the clockwise and counterclockwise torques.

Case 3. Place an unknown mass at the 10-cm mark of the meter stick. Suspend from the other side of the center of mass of the meter stick a counter mass m_2 = 200 g and adjust its position until the system is in static equilibrium. Using, $\Sigma\tau = 0$, calculate the unknown mass m_1. Remove the unknown mass and determine its mass on the laboratory balance. This is the accepted mass. Calculate % error.

Case 4. Suspend a mass m_1 = 100 g at or near the zero end of the meter stick. Move the meter stick in the support clamp until the meter stick is in equilibrium. Record this new equilibrium position as x_o'. Using the total mass of the meter stick, calculate the clockwise and counterclockwise torques, and then calculate a percent difference. In this calculation, you will include the mass of the meter stick as if it were concentrated at its center of mass, x_o (around the 50 cm mark) calculating the lever arm to the new pivot point.

Lab Report

Your Lab Report will consist of three parts:

- This lab hand out with the Data Table completed.
- An attached sheet of paper showing the diagram and calculations for EACH CASE. There should be four (4) diagrams and four (4) sets of calculations.
- One sheet of paper listing three sources of error. Estimate the size of these errors and describe the impact each of these errors had on your results.

Comparison Formulas

% Difference = $100\ (\tau_{cc} - \tau_{cw})\ /\ [(\tau_{cc} + \tau_{cw})/2]$

% Error = $100\ (m_{calc} - m_{meas})/m_{meas}$

Common Mistakes

- Mis-orienting the meter stick balance clamp with the tightening screw pointing up. Leads to an unstable system that will not balance.
- Forgetting to measure the mass of the meter stick with no clamps. Causes errors in Case 4.
- NOT including the mass of the weight hanger and its clamp in the Total Mass when calculating the torque. % Diff values will be too large.
- Using direct meter stick scale measurements (x_i) instead of the lever arm (r_i) values in the torque calculations. Major mistake - Calculations will be way off.

DATA TABLE

Mass of the meter stick: $m_{meter\ stick}$ ___________________(grams)

Mass of the Fulcrum Clamp: __________________(grams)

Mass of Clamp with V-wire: _________________(grams)

Mass of Weight Hanger: ___________________(grams)

Balancing point (center of mass) of meter stick, x_0 = _____________(cm)

Values	Moment (lever) arms	Results *(see note above)
Case 1 m_1 = 100 g x_1 = 15 cm m_2 = 200 g x_2 =__________	r_1 = ____________ r_2 = ____________	τ_{cc} = ____________ τ_{cw} = ____________ % Diff. ___________
Case 2 m_1 = 100 g x_1 = 20 cm m_2 = 200 g x_2 = 60 cm m_3 = 50 g x_3 = ________	r_1 = ____________ r_2 = ____________ r_3 = ____________	τ_{cc} = ____________ τ_{cw} = ____________ % Diff. ___________
Case 3 m_1 = ________ x_1 = 10 cm m_2 = 200 g x_2 =__________	r_1 = ____________ r_2 = ____________	m_1 _____________ (measured on scale/ accepted) m_1 _____________ (calculated, experimental) % Error ________
Case 4 m_1 = 100 g x_1 = _________ $m_{meter\ stick}$ = __________ x_o = ________ x_o' = ________ (new pivot point)	r_1 = ____________ r_2 = ____________	τ_{cc} = ____________ τ_{cw} = ____________ % Diff. ________