Experiment 8: Torques and Rotational Motion

Figure 8.1: The wood block provides necessary height for the hangers to not touch the table.

Figure 8.2: Clamp - The arrow indicates the correct edge for position measurement.

**EQUIPMENT**

Fulcrum
Meter Stick
Vernier Caliper
(3) Mass Hangers
Masses
(3) Hanger Clamps (Clamps)
(1) Knife-Edge Clamp
Digital Balance
Triple-Beam Balance
Block of Wood
Unknown Mass (Marble or “Silver” Cube)

*TA’s Table:*

(1) Dial-O-Gram Balance
**Advance Reading**

*Text:* Torque, center of mass, stable and unstable equilibrium, lever arm

*Lab Manual: Appendix A*

**Objective**

To measure torques on a rigid body, to determine the conditions necessary for equilibrium to occur, to perform error analysis.

**Theory**

When a force $F$ is applied to a rigid body at any point away from the center of mass, a torque is produced. Torque, $\tau$ (Greek letter, *tau*), can be defined as the tendency to cause rotation. The magnitude of the vector is:

$$\tau = rF \sin \theta$$  \hspace{1cm} (8.1)

where $r$ is the distance from the point of rotation to the point at which the force is being applied (*i.e.*, lever arm), and $F \sin \theta$ is the component of the force perpendicular to $r$. Note that the unit for torque is mN (meter × newton).

In this experiment, all forces will be acting normal (perpendicular) to the meter stick: $\theta = 90^\circ$; therefore, $\sin \theta = 1$. The equation for torque is simplified:

$$\tau = rF$$  \hspace{1cm} (8.2)

*Equilibrium,* Latin for *equal forces* or *balance,* is reached when the net force and net torque on an object are zero. The first condition is that the vector sum of the forces must equal zero:

$$\mathbf{\Sigma F} = \mathbf{\Sigma F}_x = \mathbf{\Sigma F}_y = \mathbf{\Sigma F}_z = 0.0 \text{ N}$$  \hspace{1cm} (8.3)

The second condition that must be met is that the net torques about any axis of rotation must equal zero. We will use the standard convention for summing torques. Torques that tend to cause counterclockwise rotation, $\tau_{cc}$, will be positive torques, while torques that tend to cause clockwise rotation, $\tau_c$, will be negative torques.

$$\mathbf{\Sigma \tau} = \mathbf{\Sigma \tau}_{cc} - \mathbf{\Sigma \tau}_c = 0.0 \text{ mN}$$  \hspace{1cm} (8.4)

The system under consideration for this experiment will need to not only attain equilibrium, but also remain in equilibrium. This will require that the object be in *stable equilibrium,* meaning if a slight displacement of the system occurs, the system will return to its original position (*e.g.*, a pendulum). If the system were to move farther from its original position when given a slight displacement, it would be in *unstable equilibrium* (*e.g.*, a ball on a hill).

Once stable equilibrium has been attained for each experimental arrangement, measure the mass at each position using the appropriate balance.

![Figure 8.3: Required sketch for each experimental arrangement](image-url)
1. Define torque, and state the conditions necessary for stable equilibrium. (20 pts)

2. Why are the following equations equivalent for this experiment? (20 pts) \[ \tau = rF \sin \theta \quad \tau = rF \]

3. Refer to the procedure, Part 1, 1st arrangement. Assume \( x_{cm} = 50.0 \text{ cm} \), 150.0 g is suspended from a hanger clamp at the position \( x_c = 15.0 \text{ cm} \), and a hanger clamp is at position \( x_c = 75.0 \text{ cm} \). If each hanger clamp has a mass \( m = 16.5 \text{ g} \), what mass must be added to \( x_c \) in order to attain stable equilibrium? Sketch a diagram of the situation (refer to Fig. 8.3). (30 pts)

4. Consider Part 2 of the procedure. Determine the additional mass required for stable equilibrium. Meter stick: \( x_{cm} = 50.0 \text{ cm}, m = 150.0 \text{ g} \). Hanger clamp: \( x_{cc} = 0.0 \text{ cm}, m = 16.5 \text{ g} \). (30 pts)
**PROCEDURE**

**PART 1: Quantitative Analysis of Torque**

1. Place the knife-edge clamp at the 50 cm position of the meter stick with the screw pointing down. Adjust the knife-edge clamp until the meter stick is balanced and horizontal (stable equilibrium). Record this position as $x_{cm}$.

2. Place a clamp at the $x = 15$ cm position and hang 200 g from it.

3. Place another clamp at the $x = 75.0$ cm position. Add enough mass to attain equilibrium. If small fractional masses are not available to you, it may be necessary to adjust the position of the 75 cm clamp in order to balance the system.

4. Measure the mass at each position; recall that the digital balance has a limit of 0.2 kg.

5. Determine the force, radius, and torque at each position.

6. Calculate the sum of the torques.

**PART 2: One-Person See-Saw**

7. Remove all clamps from the meter stick. Measure and record the mass of the meter stick.

8. Place the fulcrum at 20 cm on the meter stick.

9. Place a clamp as close to the zero end as possible. Add mass incrementally to attain static equilibrium. Measure this mass.

10. Make a torque-balance sketch similar to the one in Step 6; fill it in with the appropriate values. Calculate the net torque about the fulcrum. Note that the meter stick behaves as though all of its mass is concentrated at its center of mass.

**PART 3: Unknown Mass**

11. Determine the mass of a metal cube experimentally, using the torque apparatus however you choose.

12. Make a torque-balance sketch of your experimental setup.

13. Determine the density of the metal cube by measuring its dimensions.

14. Identify the metal using the density chart provided in Table 1.1 (Page 9). Compare your value of density to the accepted $\rho$ value for that material.

**QUESTIONS**

1. Consider the Dial-O-Gram balance and the triple-beam balance. The Dial-O-Gram balance has a spring, calibrated for Earth, behind the dial. This spring exerts a force that allows accurate measurement of mass. The triple-beam balance uses only the principles of torque, which you investigated in this experiment. Will either balance allow us to accurately measure the mass of an object on the moon?

2. Calculate $\delta \Sigma \tau$ for each $\Sigma \tau$ you determined in Part 1, Part 2, and Part 3. Is each $\Sigma \tau$ within experimental uncertainty?