

## LAB: TORQUE & EQUILIBRIUM

**Physics in the Wild:** You're about to do exactly what a structural engineer does — predict where forces must act to keep a structure from rotating, then verify with real measurements.

### PURPOSE

Verify that when an object is in static equilibrium, the net torque about any pivot point equals zero.

### EQUIPMENT

- Meter stick
- Fulcrum (knife-edge)
- Hanging masses: 50 g, 100 g, 200 g, 500 g
- Mass hangers (if needed)
- Digital scale
- String loops

### KEY EQUATION

$$\text{Equilibrium Condition: } \Sigma\tau = 0$$

$$\text{Torque Definition: } \tau = r \times F \times \sin(\theta)$$

$$\text{For hanging masses } (\theta = 90^\circ): \tau = r \times mg$$

### PRE-LAB PREDICTION

#### **PREDICT** Balance a Meter Stick

A 100 g mass hangs at the 20 cm mark on a meter stick balanced at the 50 cm mark. Where should a 200 g mass be placed to balance?

**Your prediction:**

**PART A: VERIFY  $\Sigma\tau = 0$  WITH KNOWN MASSES****Procedure:**

1. Find the balance point of the bare meter stick. Record the center of mass position.
2. Place the fulcrum at the 50.0 cm mark.
3. Hang a 200 g mass at the 15 cm mark. The stick tips.
4. Hang a 100 g mass on the other side. Adjust its position until the stick balances.
5. Record the position. Calculate torques from both masses AND from the stick's weight (if  $\text{COM} \neq 50 \text{ cm}$ ).
6. Repeat with different mass combinations (3 total trials).

**DATA: PART A**

Trial	Mass 1 (kg)	Pos 1 (cm)	$r_1$ (m)	$\tau_1$ (N·m)	Mass 2 (kg)	Pos 2 (cm)	$r_2$ (m)	$\tau_2$ (N·m)	$\Sigma\tau$ (N·m)
1									
2									
3									

Stick COM correction (if needed)

**ANALYSIS**

How close is  $\Sigma\tau$  to zero? Calculate percent difference for each trial.

**PART B: FIND AN UNKNOWN MASS****Procedure:**

1. Your teacher will give you an unknown mass (do NOT weigh it yet).
2. Hang the unknown at the 20 cm mark.
3. Use a KNOWN mass (200 g) and adjust its position to balance.
4. Use  $\Sigma\tau = 0$  to CALCULATE the unknown mass.
5. Now weigh the unknown on a scale. Compare.

**DATA: PART B**

Unknown Pos (cm)	r_unknown (m)	Known Mass (kg)	Known Pos (cm)	r_known (m)	Calculated Unknown (kg)	Measured Unknown (kg)	% Error

**ANALYSIS QUESTIONS**

- (a) What was your percent error? Is this acceptable for a physics lab?
- (b) List 2 sources of systematic error in this experiment.
- (c) A student says "I can put the pivot anywhere and still get  $\Sigma\tau = 0$ ." Is this true? Test it: recalculate Part A Trial 1 using the 30 cm mark as your pivot instead. Do you still get  $\Sigma\tau \approx 0$ ?

**EXTENSION: TWO-PIVOT CHALLENGE****CHALLENGE** **Beam on Two Supports**

The stick is now supported at TWO points (the 20 cm mark and the 80 cm mark). A 500 g mass hangs from the 60 cm mark. Find the support force at each pivot. (This is exactly the beam-on-two-supports problem from Day 4, but now with real equipment.)

**AP Connection:** On the AP exam, lab questions often ask: "Describe an experiment to verify..." You just did it. Be able to describe the procedure, identify what you measured vs. calculated, and explain sources of error.

**CONCLUSION**

In 2-3 sentences, state what you verified and how your data supports (or doesn't support) the equilibrium condition.

**Clean Up:** Return all masses to the tray. Stack meter sticks neatly.