Name: ______________________________ Section: __________ Date: ____________

Worksheet - Exp 8: Torques and Rotational Motion

Objective: This experiment investigates torque on a rigid body and determines the conditions necessary for static equilibrium.

Theory: When a force $\vec{\mathbf{F}}$ is applied to a rigid body at any point away from the center of mass, a torque is produced. Torque, τ, can be defined as the tendency to cause rotation. The magnitude of the vector is:

$$\tau = rF\sin\theta$$

where r is the distance from the point of rotation to the point at which the force is being applied, and $F\sin\theta$ is the component of the force perpendicular to r. Note that the unit for torque is the mN (m $\times$ Newton). In this experiment, all forces will be acting normal (perpendicular) to the meter stick: $\theta = 90°$. Therefore $\sin\theta = 1$, and the equation for torque is simplified:

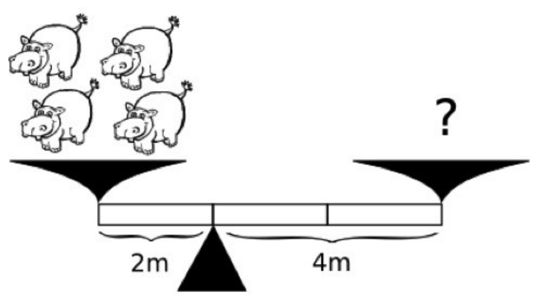
$$\tau = rF.$$

Rotational *equilibrium* is obtained when the sum of torques about any axis is equal to zero.

$$\sum \vec{\tau}_{\mathbf{cc}} - \sum \vec{\tau}_{\mathbf{c}} = 0.0 \text{ mN}$$

1. Four hippopotamuses sit on one side of a scale as shown. How many hippos placed on the right side of the scale would balance the system?

   ____________ (5 pts)



2. How much torque does a hubcap (4 kg) exert when mounted to the center of a wheel of a car (radius = 0.5 m)? (5 pts)

   ____________ mN

Procedure:

Part 1: Quantitative Analysis of Torque

3. Measure the mass of the hanger clamps (m_{hc}), record this data below. You will need it throughout the experiment.

   m_{hc} = ________________

4. 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 the position as x_{cm} (center of mass position), and x_f (fulcrum position).

5. Place a clamp at the x_{cc}=15.0 cm position (position of counter-clockwise torque) and hang 200 g from it.

6. Place another clamp an the x_c=75.0 cm position (position of clockwise torque). 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.

7. Measure the mass at each position; recall that the digital balance has a limit of 0.2 kg. **Don't forget to include the mass of the clamps!**

8. Determine the radius from the fulcrum, mass, force, and torque at each position.

x_{cc} = ________ x_f = ________ x_{cm} = __________ x_c = _________

r_{cc} = _______________ r_c = ________________

m_{cc} = _____________ m_c = ____________________

F_{cc} = _____________ F_c = ____________________

τ_{cc} = _____________ τ_c = ____________________

(18 pts)

9. : Calculate the sum of the torques. (Note that the torques are in opposite directions, if one is positive, the other must be negative.) (3 pts)

   $\sum \tau$ = ________________

10. Explain how a triple-beam balance works (5 pts). Would such a balance that functions properly on earth yield the correct mass of an object on the moon? Why or why not? (5 pts)

Part 2: One-Person See-Saw

11. Remove all hanger clamps from the meter stick and move the knife edge clamp to the 20 cm position. Place the meter stick on the fulcrum at the 20 cm position.

12. Place a clamp at the 1 cm position. Add mass incrementally to attain static equilibrium. Measure this mass (don't forget about the clamp!)

13. Fill in the diagram below with the appropriate values. Note that the meter stick behaves as though all of its mass is concentrated at its center of mass (determined in step 4), and the position of the fulcrum is no longer same as center of mass. Using this information calculate the mass of the meter stick.

x_{cc} = ________ x_f = ________ x_{cm} = ________ x_c = ________

r_{cc} = ____________ r_c = ____________

m_{cc} = ____________ m_c = ____________

F_{cc} = ____________ F_c = ____________

τ_{cc} = ____________ τ_c = ____________

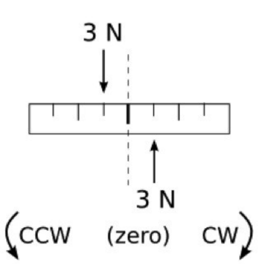
(18 pts)

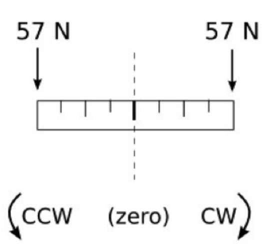
14. Measure the mass of the meter stick on the triple beam balance and compare to the mass determined in step 13.

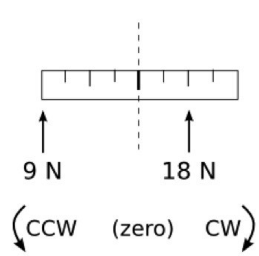
% Error: ________________ (10 pts)

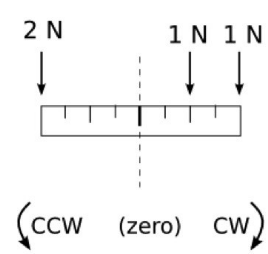
Summing Torques

In each of the four diagrams below, indicate (circle) whether the system experiences a net torque counterclockwise (ccw), clockwise (cw), or net zero torque. [Note: Some forces act upwards.] (3 pts ea.)









Part 3: Unknown Mass

15. Determine the mass of a metal cube experimentally, using the torque apparatus however you choose. It is imperitive that you use the cube at your table. If you do not have one, ask your TA for help, do not simply get one from a different table.

16. Record your table number: ____________

17. Make a torque-balance sketch of your experimental setup below. (6 pts) m_{block} = _______________ (2 pts)

18. Determine the density of the metal cube by measuring its dimensions with the digital caliper and mass using your torque apparatus. (5 pts)

ρ_{block} = __________________

Material: ________________________ (4 pts)

Density %error: __________________ (3 pts)

Material	***Density (g/cm³)***
Solids	
Metal:	
Aluminum	2.70
Stainless Steel	7.8
Brass	8.44 - 8.75
Bronze	8.74 - 8.89
Copper	8.96
Lead	11.3
Mercury	13.5336
Rock:	
Granite	2.64 - 2.76
Slate	2.6 - 3.3
Diamond	3.51
Garnet	3.15 - 4.3
Corundum	3.9 - 4.0
Wood:	
Pine (Yellow)	0.37 - 0.60
Oak	0.60 - 0.90
Ebony	1.11 - 1.33
Misc.:	
Ice	0.917
Bone	1.7 - 2.0
Chalk	1.9 - 2.8
Glass (Lead)	3 - 4
Fluids	
Atmosphere (STP)	0.001225
Water (20°C)	0.99821
Water (0°C)	0.99984
Mercury (20°C)	13.546