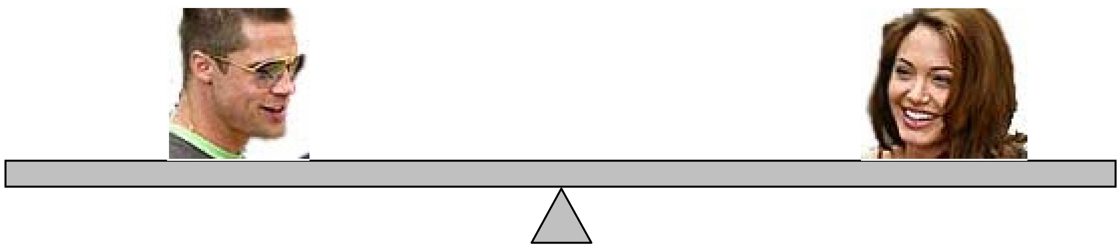
Experiment: Torque & Rotation

Objectives

- To compare the rotational motion of objects rolling down an incline
- Calculate the moment of inertia for various objects
- To apply the concept of torque and mechanical equilibrium to a balanced meter stick
- Calculate the mass of a meter stick knowing the conditions of equilibrium of a rigid body

Preliminary Questions:

In their final appearance in the physics lab, Brad and Angelina are sitting on a teeter-totter. Ignore the effects of friction and mass of their egos as well as that of the teeter-totter.



a) Brad (with a mass of 80 kg) sits 2.0 m from the fulcrum. What is the torque exerted by Brad on the teeter-totter?

b) For the teeter-totter to balance with Angelina sitting on the opposing end, how much torque must she exert on the teeter-totter?

c) Draw a simple force vector diagram of the 2-person teeter-totter system.

d) If Angelina has a mass of 50 kg, how far from the fulcrum must she sit so that the teeter-totter balances?

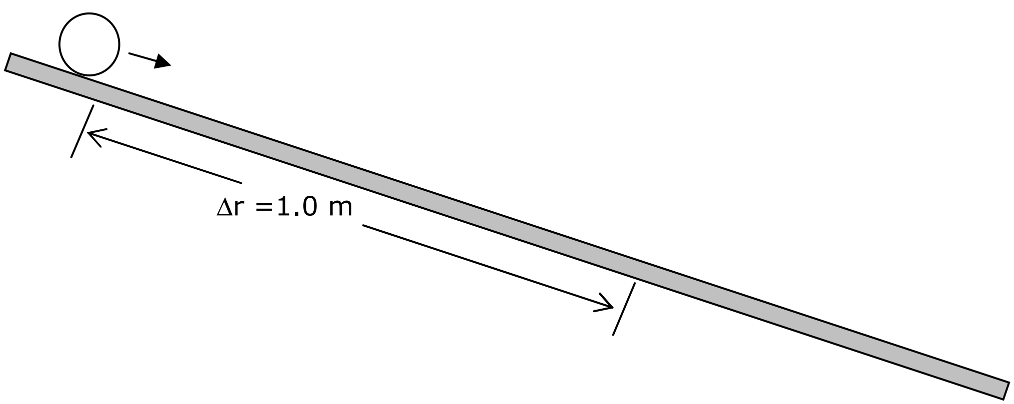
e) If the teeter-totter is balanced, does it matter where you choose the fulcrum to be when calculating the torques associated with each force exerted on it? Explain.

A) Rotational Inertia

1) Obtain a hollow cylinder (a tin can with both ends cut out), a solid can (a full can of "ravioli" ought to do the trick), a solid (steel bearing) and a hollow sphere (racquetball).
2) Measure the mass and radius of each object. Record values in Table 1.

Table 1: Initial Measurements			
Object	**Mass (kg)**	**Radius, R (m)**	**Moment of Inertia ( )**

3) Using a collision track, set-up a ramp at a slight incline. Measure and record the angle of the incline.



4) Measure a 1.0 m distance along the incline. Use tape to mark the beginning and end points.
5) Using a stop watch, measure the time it takes for the hollow cylinder to roll 1.0 m down the ramp. Record the distance and time in Table 2.
6) Repeat for each object.

Table 2: Experimental values				
Object	$\theta_{incline}$	$\Delta r_{along\ ramp}$ **(m)**	Δt **(s)**	a_{avg} **(m/s²)**

Question: Which object reached the bottom in the shortest amount of time? Arrange the objects in order time (shortest to longest).

7) Calculate the magnitude of the average acceleration of each object. Use the following equation from kinematics:

$$\left|a_{avg}\right| = \frac{2\Delta r}{t^2}$$

Record the acceleration values in the table above.

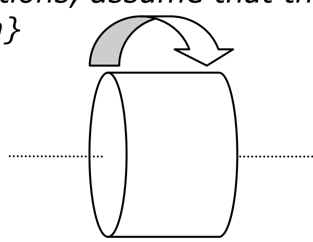
Question: Arrange the objects in order of average acceleration (highest to lowest).

Analysis:

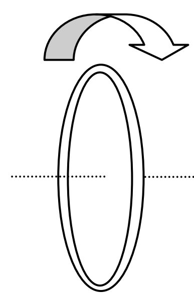
1. Calculate the moment of inertia for the corresponding objects:

{For these calculations, assume that the mass (m) of each object is 0.1 kg and the radius, R, is 0.5 m}

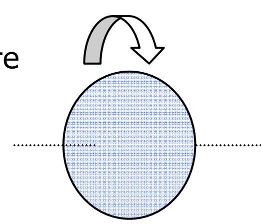
a) a solid disc



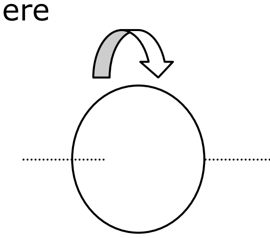
b) a ring (or hollow cylinder)



c) a solid sphere



d) a hollow sphere



2. Which of the above objects has the smallest rotational inertia? Arrange the objects in order their rotational inertia (low to high).

3. How does the order of rotational inertia values compare with the order of time and acceleration values above?

4. How can you reconcile that the discrepancy between the order of the moments of inertia vs. the accelerations for the various objects?

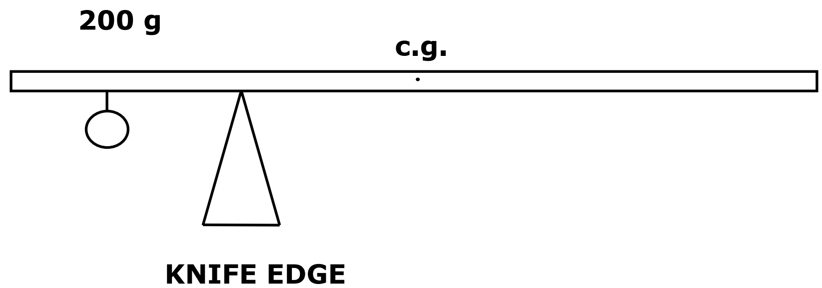
5. Estimate the velocity, angular velocity, translational KE and rotational KE for each object at the bottom of the ramp. *Try using the Law of Conservation of Mechanical Energy.*

B) Mechanical Equilibrium & Torque:

1) Find the position of the knife-edge that balances the meter stick (do not weigh the meter stick ahead of time). This locates the center of gravity for the meter stick.

2) Attach a 200 gram mass at the 90 cm position.

3) Re-adjust the position of the knife edge such that the meter stick is once again balanced.



4) In the above diagram, sketch and label the forces exerted on the meter stick.

5) Apply Newton's 2nd Law to the meter stick:

Force:

Torque:

6) From the conditions of mechanical equilibrium, $\vec{F}_{Net} = 0$ and $\vec{\tau}_{Net} = 0$, determine the mass of the meter stick and estimate the uncertainty ($\boldsymbol{\delta m_{meter\ stick}}$) of this value.

$\mathbf{m_{meter\ stick}}$ **=** ________________ *(Calculated)*

$\boldsymbol{\delta m_{meter\ stick}}$ **=** ________________ *(Estimated)*

7) Check this value by directly measuring the mass of the stick. Calculate the % error.

$\mathbf{m_{meter\ stick}}$ **=** ________________ (*Measured)*

% Error = ________________

7) Calculate each torque exerted on the balanced meter stick using one end of the meter stick as the fulcrum (or "axis of rotation").