Newton's 2nd Law for Rotation

Equipment

1	Rotary Motion Sensor	PS-2120A
1	Rotational Accessory	CI-6691
1	Clamp-on Pulley	(in CI-6691)
1	Thread	(in CI-6691)
1	Mass and Hanger Set	ME-8979
1	45 cm Rod	ME-8736
1	Large Rod Base	ME-8735
	Required but not included:	
1	Meter Stick	SE-8827
1	Calipers	SE-8710
1	Balance	SE-8723

Introduction

Newton's 2nd Law states that the resulting acceleration (a) of an object is directly proportional to the net Force (F) on that object.

$$F = ma \qquad (1)$$

where the proportionality constant (m) is the mass or inertia of the object.

We can also write Newton's 2nd Law for rotation: The resulting angular acceleration (α) of an object is directly proportional to the net torque (τ) on that object.

$$\tau = I\alpha \qquad (2)$$

where the proportionality constant (I) is the rotational inertia of the object.

Written by Jon Hanks

Figure 1: The hanging mass applies a torque to the shaft of the Rotary Motion Sensor and the resulting angular acceleration of the rod and brass masses is investigated.

Setup: Apply Torque by Hand

1. Use the Large Rod Base and the 45 cm Rod to support the Rotary Motion Sensor as shown in Figure 1. Plug the sensor into the interface.

2. Use calipers to measure all three radii on the clear Three-step Pulley.

3. Attach the black rod from the Rotation Accessary to the clear pulley (see Fig. 2) with the two brass masses near the end of the rod.

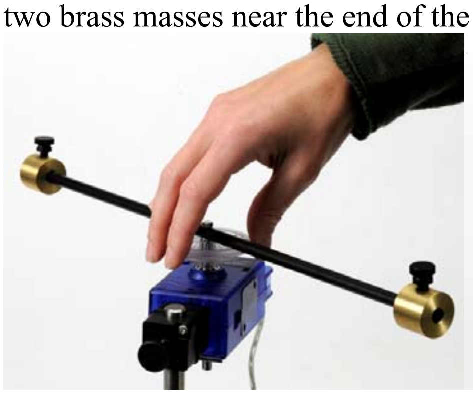

Figure 2: Mass at Large Radius

Figure 3: Mass at Small Radius

4. Plug the Rotary Motion Sensor into the interface.

5. In PASCO Capstone, set the sample rate to 20 Hz. Create a graph of angular velocity vs. time.

6. Click on Record. Grab the clear pulley and try to rotate the rod back and forth as fast as possible. Click on Stop.

7. Move the brass masses closer to the center as shown in Figure 3, and repeat. Which was easier? What does that tell you about rotational inertia?

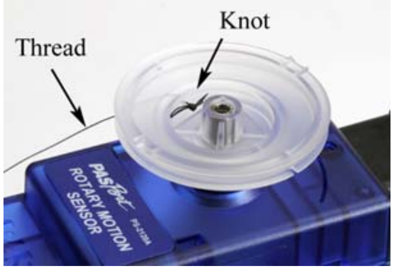

Figure 5: Attaching Thread to Pulley

Apply Constant Torque

8. Cut a piece of thread about 75 cm long. Run the thread through the hole in the medium size pulley, and tie a large knot as shown in Figure 5.

9. The thread will naturally wind up on the medium pulley. Using the slots, you can force the string to wind up on the small radius or the large radius as shown in Figure 6.

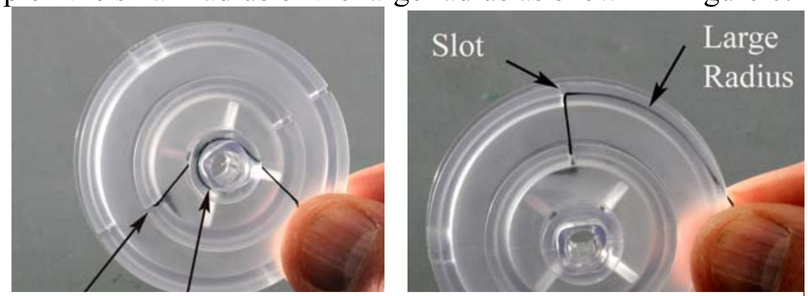

Figure 6: By running the thread through the slot, you can change the radius that the thread is wound around without having to re-tie the thread.

10. Clamp the black pulley onto the Rotary Motion Sensor as shown in Figure 7. Note how the pulley is clamped at an angle to match the tangent to the clear Three-step Pulley. It must also be adjusted vertically using the two thumbscrews, to match the height of the clear pulley being used. Each time you change to a different radius pulley, you will have to re-adjust both the angle and height.

11. Connect a mass hanger to the end of the thread. Adjust the length so that it doesn't quite hit the table. Add a 100 g mass to the hanger.

12. When you wind up the thread onto the Three-step Pulley, make sure the thread winds smoothly with no overlaps. Also, do not place too much thread on the pulley: You only want a single layer of thread, so that the radius stays constant.

Figure 7: Adjusting Angle of Clamp-on Pulley

Procedure – Calculating Inertia

1. Using a meter stick, position the brass masses on the black rod as accurately as possible so that their center of mass is at a radius of 18 cm from the center of rotation.

2. Adjust the pulley for the middle pulley, and wind on a few turns of thread.

3. Click on Record and release the rod. Click on Stop before you get to the end of the thread.

4. Look at the graph. It makes the lab easier if the velocity is positive. To change the sign, wind the thread up in the opposite direction, or you can change the sign of the measurement in the Properties for the sensor.

5. Get a single good positive run and rename this run "medium".

6. Use a linear curve fit to find the slope of the line. If the data is not straight, use the Highlight tool to select data from the beginning of the run when it is moving slower. This should be more accurate because the friction is less.

7. What is the physical significance of the slope? What are the units?

8. Calculate the torque applied by the hanging mass.

   $$\text{torque} = \tau = rF \qquad (2)$$

   where r is the radius of the Three-step Pulley and F is the weight of the hanging mass. Don't forget the mass of the hanger!

9. Use Equation (2) to calculate the rotational inertia (I). Simplify the units as far as possible. The only terms should be mass and length.

Note: The tension in the thread is actually slightly less than the weight of the hanging mass, due to the downward acceleration. Since this has such a small effect for this lab, we can ignore it!

Vary Torque

10. Leaving all other parameters the same, you will now take a run of data using the large pulley on the Three-step Pulley. Adjust the black pulley for the large pulley, and wind on a few turns of thread. Make sure that it is wound on the large pulley. Look at Figure 6 if you have problems.

11. Get a good run of data like before. Rename this run "large"

12. Is the angular acceleration the same? Should it be?

13. Use Equation (3) to calculate the new torque.

14. Use Equation (2) to calculate the rotational inertia (I). Do you get about the same value? Should it be?

15. Now take a run of data using the Small pulley. Do you get about the same value for the rotational inertia? What do you conclude?

16. Leaving all other parameters the same, you will now take a run of data using a different hanging mass. Replace the 100 g mass with a 50 g mass, but keep using the small pulley.

17. Calculate the rotational inertia as before. What do you conclude?

18. In the next part (following pages), you will apply a constant torque. Do not change the hanging mass, and continue to use the small pulley.

Constant Torque

19. Position the brass masses on the rod so that their center of mass is at a Radius (R) of 4 cm from the center of rotation.

20. Create a table with two columns. In the first column, create a User-Entered Data set called "Radius R" with units of m. Fill the values in as shown below. In the second column, create a User-Entered Data set called "α" with units of rad/s^2.

	Radius R (m)	α (rad/s²)
1	0.04	
2	0.06	
3	0.08	
4	0.10	
5	0.12	
6	0.14	
7	0.16	
8	0.18	

21. Get a good run of data, and determine the angular acceleration from the slope of the angular velocity vs. time graph. Rename this run "4 cm", and record your value in the table.

22. Repeat for the other radii listed. Remember: Always make sure you are using the small radius on the three-step pulley.

Calculating Inertia

1. Open the Calculator window and create a calculation for the rotational inertia:

   $I = \tau/[\alpha\ (rad/s^2)]$ with units of kg m^2.

   Add a column to the table and insert this calculation.

2. For one data set in the table, calculate the rotational inertia yourself to confirm that the calculation is correct. Remember that "R" is the position of the brass masses (measured from the center of rotation) and "r" is the radius for the three-step pulley.

3. Create a graph of I vs. Radius R.

4. Is the graph linear? Pick a QuickCalc on the horizontal axis to change to R^2.

5. Use a linear fit to find the slope of the straight line. What are the units? What is the physical significance of the slope?

6. Use a balance scale to measure the actual mass of the two brass masses and compare to the calculated value.

7. What is the physical significance of the y-intercept from your graph? What else besides the brass masses has inertia?

8. Write a theoretical equation for the rotational inertia of a point mass (M), moving around a circle of radius (R).