

Rotary Motion Sensor

PS-2120A

Contents

Using the Rotary Motion Sensor with Data Collection Software 1

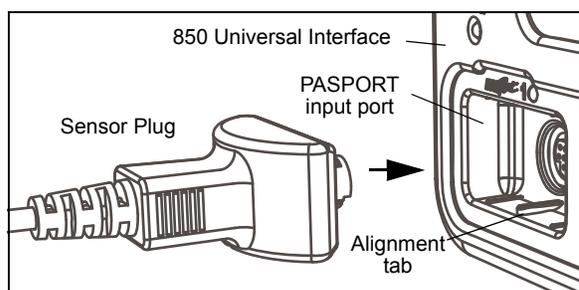
Experiment 1: Rotational Inertia of a Point Mass 3

Experiment 2: Rotational Inertia of Disk and Ring 5

Experiment 3: Conservation of Angular Momentum 7

Using the Rotary Motion Sensor with Data Collection Software

- Plug the Sensor Plug into a PASPORT input port of a PASPORT-compatible PASCO interface..
- Turn on the PASPORT-compatible interface.



Software Help

See the SPARKvue Help or PASCO Capstone Help for information about collecting, displaying, and analyzing data.

- In SPARKvue, select the **HELP** button () in any screen including the Home Screen.
- In PASCO Capstone, select **PASCO Capstone Help** from the **Help** menu, or press **F1**.

SPARKvue

Collect Data

- In the SPARKvue **Home Screen**, select a measurement from the list under the sensor's name. A graph of the measurement versus time opens.
- In SPARKvue, select the **Start** button () to begin collecting data.

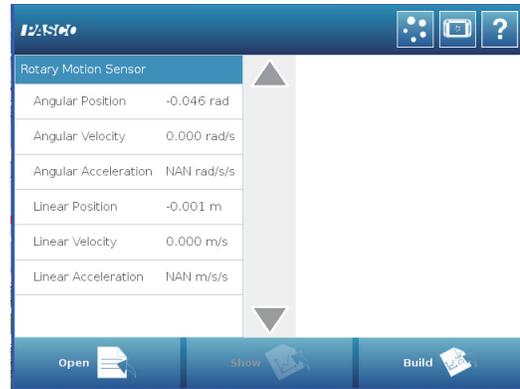
PASCO Capstone

Collect Data

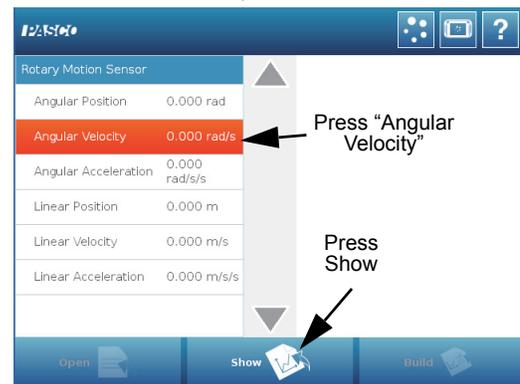
- In PASCO Capstone, select a display in the main window or from the **Display** palette. In the display, use the **<Select Measurement>** menu to pick a measurement to be shown.
- Select **Record** to begin collecting data.

SPARKvue Setup

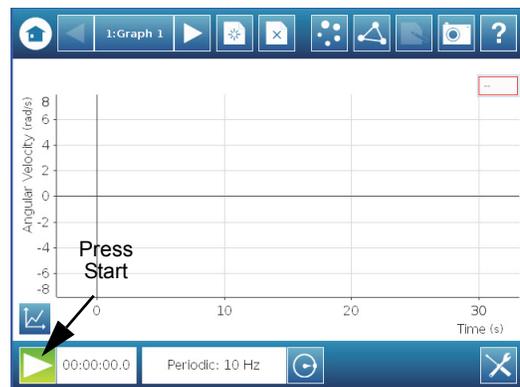
- In the Home Screen, press “Angular Velocity” and then press the Show button () to open a graph display.
- Press the Start button () to begin recording data. Turn the shaft of the sensor and view the data in the display.
- Press the Stop () button to end data recording.
- SETUP:** For detailed information on setting up the data collection software and recording data, refer to the User’s Guide and the online help for the data collection software.



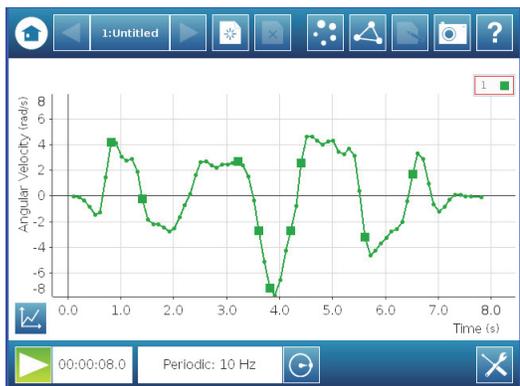
SPARK SLS Home Screen for the Rotary Motion Sensor



Press “Angular Velocity” and then press “Show”



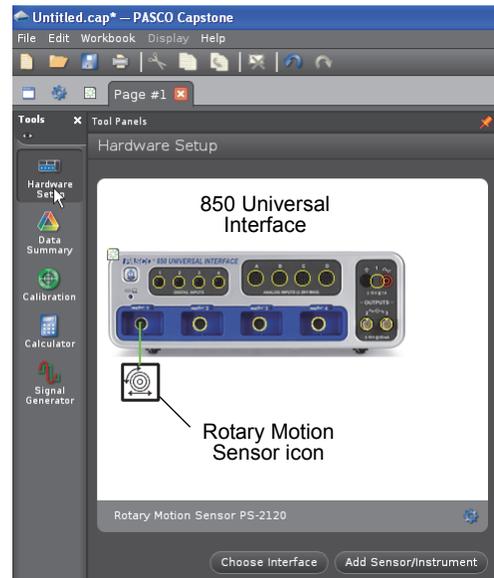
Press “Start”



Turn the Rotary Motion Sensor shaft

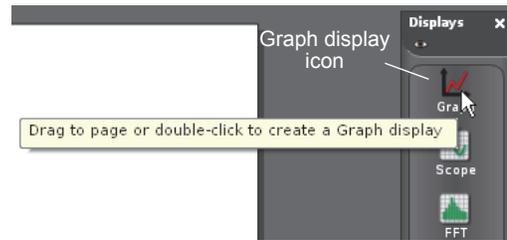
PASCO Capstone Setup

- In PASCO Capstone, click “Hardware Setup” in the Tools palette to open the Hardware Setup panel. Confirm that the Hardware Setup panel shows the interface you are using and the icon of the Rotary Motion Sensor.



Capstone Hardware Setup panel

- Set up a data display. For example, drag the Graph icon from the Displays palette onto the workbook page, or double-click the icon to create a Graph display..



Create a Graph display

- Set up the Graph display to show Angular Velocity (rad/s) on the vertical axis. Click the “Select Measurement” menu button on the vertical axis and pick Angular Velocity (rad/s) from the menu. Time (s) automatically shows on the horizontal axis.
- Click ‘Record’ in the lower left corner of the PASCO Capstone window to begin recording data. (The “Record” button changes to



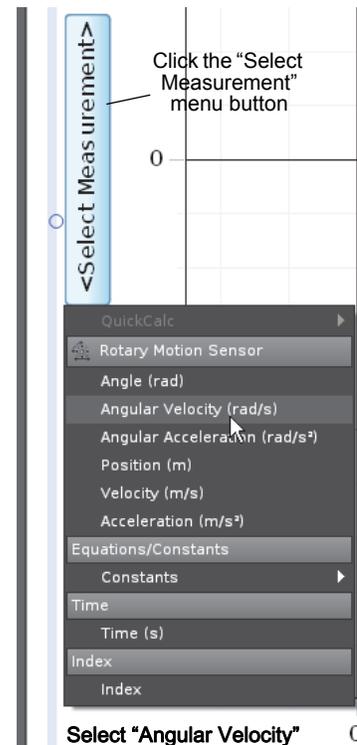
Click “Record”

“Stop”.)

- Turn the shaft of the Rotary Motion Sensor back-and-forth. View the data in the Graph display.
- Click “Stop” to end data recording.



Click “Stop”



- SETUP:** For detailed information on setting up the data collection software and recording data, refer to the User’s Guide and the online help for the data collection software.

Technical Support

For assistance, contact PASCO:

Address: PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100

Phone: +1 916-786-3800 (worldwide)
800-772-8700 (U.S.)

Web: www.pasco.com

Email: support@pasco.com

Experiment 1: Rotational Inertia of a Point Mass

Equipment Required*	Equipment Required*
PASPORT-Compatible Interface	Rotary Motion Sensor (PS-2120A)
Mini-Rotational Accessory (CI-6691)	Mass and Hanger Set (ME-8979)
Base and Support Rod (ME-9355)	Triple Beam Balance (SE-8723)
Paper clips (for masses <1 g)	Calipers (SF-8711)

*Click the equipment item to go to the PASCO web site.

Purpose

The purpose of this experiment is to find the rotational inertia of a point mass experimentally and to verify that this value corresponds to the calculated theoretical value.

Theory

Theoretically, the rotational inertia, I , of a point mass is given by $I = MR^2$, where M is the mass, and R is the distance the mass is from the axis of rotation. Since this experiment uses two masses equidistant from the center of rotation, the total rotational inertia will be

$$I_{total} = M_{total}R^2$$

where $M_{total} = M_1 + M_2$, the total mass of both point masses.

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \tau/\alpha$$

where α is the angular acceleration, which is equal to a/r (a = linear acceleration), and τ is the torque caused by the weight hanging from the thread that is wrapped around the 3-step Pulley.

$$\tau = rT$$

where r is the radius of the chosen pulley about which the thread is wound, and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, m , gives

$$\Sigma F = mg - T = ma$$

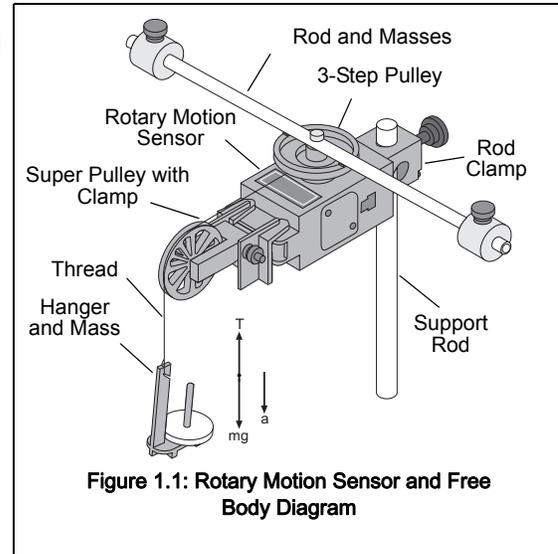
(see Figure 1.1). Solving for the tension in the thread gives:

$$T = m(g - a)$$

After the angular acceleration of the mass (m) is measured, the torque and the linear acceleration can be obtained for the calculation of the rotational inertia.

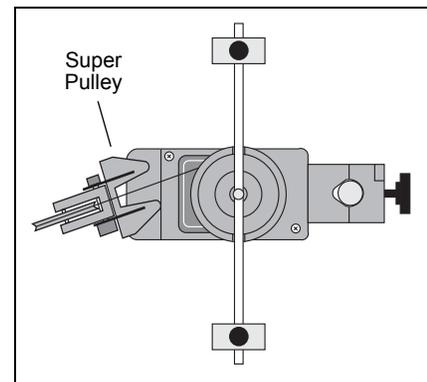
Equipment Setup

1. Attach a mass on each end of the rod (part of the Mini-Rotational Accessory) equidistant from the rod center. You may choose any radius you wish.
2. Tie one end of a thread to a Mass Hanger and tie the other end to one of the levels of the 3-step Pulley on the Rotary Motion Sensor (RMS).
3. Mount the rod and masses to the pulley on the Rotary Motion Sensor. Please note the orientation of the 3-step Pulley.
4. Mount the RMS on a support rod and connect it to a PASPORT-compatible interface. Make sure that the support rod does not interfere with the rotation of the rod and masses. See Figure 1.1.
5. Mount the Super Pulley with Clamp on the end of the Rotary Motion Sensor.
6. Drape the thread over the Super Pulley such that the thread is in the groove of the pulley and the Mass Hanger hangs freely (see Figure 1.1).



Note: The Super Pulley with Clamp must be adjusted at an angle, so that the thread runs in a line tangent to the point where it leaves the 3-step Pulley and straight down the middle of the groove on the clamp-on Super Pulley (Figure 1.2).

7. Adjust the Super Pulley height so that the thread is level with the 3-step pulley.
8. Connect the Rotary Motion Sensor to the interface and turn the interface on.



Procedure

Part 1: Measurements for the Theoretical Rotational Inertia

1. Weigh the two masses from the ends of the thin rod to find the total mass M_{total} and record the value in Data Table 1.
2. Measure the distance from the axis of rotation to the center of the masses and record this radius in Data Table 1

Data Table 1: Theoretical Rotational Inertia

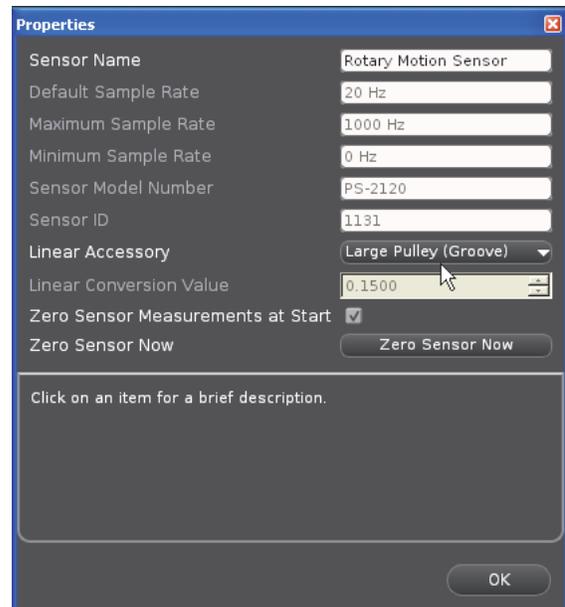
Total Mass	
Radius	

Part 2: Measurement for the Experimental Method

A. Finding the Acceleration of the Point Masses and Apparatus

1. In the data collection software, create an experiment to measure the *angular velocity* (in radians per second) versus *time* (in seconds) of the point masses and apparatus.
 - In PASCO Capstone, for example, drag the Graph icon from the Displays palette to the workbook. Select “Angular Velocity (rad/s)” for the vertical axis, and “Time (s)” for the horizontal axis.
 - Click the Hardware Setup icon in the Tools palette to open the “Hardware Setup” panel. In the panel, click the properties button (it looks like a gear wheel in the lower right corner).

- In the Properties window for Linear Accessory, select the size of the 3-step Pulley you are using. The default setting is “Large Pulley (Groove)”. Click OK.



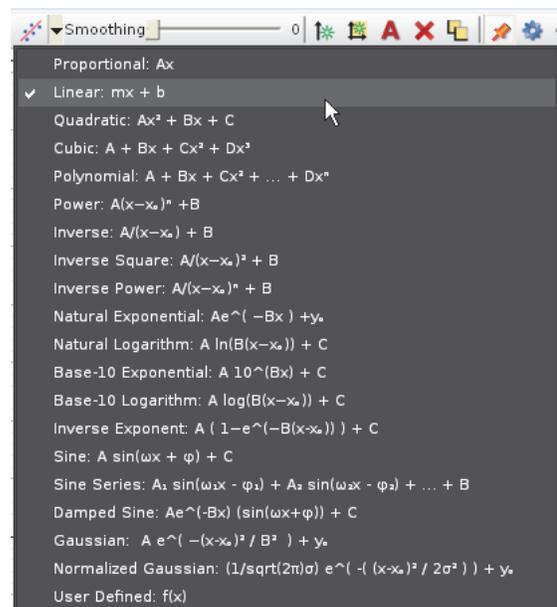
Select Size of 3-step Pulley

2. Put a 50-g mass on the Mass Hanger and turn the 3-step Pulley to wind up the thread so the hanger is just below the Super Pulley. Hold the 3-step Pulley.
3. Click **Record** to begin recording data, and release the 3-step Pulley, allowing the hanger to fall.
4. Caution! Click **Stop** to end data recording BEFORE the hanger reaches the floor or the thread completely unwinds from the 3-step Pulley.
5. In the Graph display, select the region of the data that represents when the Point Masses and Apparatus were accelerating.
6. In the display, select “Linear” from the curve fit menu.

The slope, m , of the linear fit represents the angular acceleration (α) for the Point Mass and Apparatus

7. Record the value of the slope, m , as the angular acceleration in Data Table 2.
8. Using calipers, measure the diameter of the pulley about which the thread is wrapped and calculate the radius. Record the radius in Data Table 2.

In the previous procedure, the apparatus is rotating and contributing to the total rotational inertia. The next step is to find the rotational inertia of the apparatus by itself so that this rotational inertia can be subtracted from the total.



Select “Linear” as the Curve Fit

B. Finding the Acceleration of the Apparatus Alone

1. Take the point masses off the ends of the rod.
2. Repeat the procedure from Part A for finding the angular acceleration of the apparatus alone.
 - You may need to decrease the amount of hanging mass so that the apparatus does not accelerate too fast for smooth data collection.
 - Remember that the value of the slope, m , is the angular acceleration.
3. Record the data in Data Table 2.

Data Table 2: Experimental Rotational Inertia Data

	Point Mass and Apparatus	Apparatus Alone
Hanging Mass		
Slope, m		
Radius		

Calculations

1. Calculate the experimental value of the rotational inertia of the point masses and apparatus together and record the calculation in Data Table 3.
2. Calculate the experimental value of the rotational inertia of the apparatus alone and record the calculation in Data Table 3.
3. Subtract the rotational inertia of the apparatus from the total rotational inertia of the point masses and apparatus together. Record this in Data Table 3 as the rotational inertia of the point masses alone.
4. Calculate the theoretical value of the rotational inertia of the point masses and record the calculation in Data Table 3.
5. Calculate the percent difference to compare the experimental value to the theoretical value, and record the percent difference in Data Table 3.

Data Table 3: Results

Component	Rotational Inertia
Point Masses and Apparatus Combined	
Apparatus Alone	
Point Masses (experimental value)	
Point Masses (theoretical value)	
Percent Difference	

Experiment 2: Rotational Inertia of Disk and Ring

Equipment Required*	Equipment Required*
PASPORT-Compatible Interface	Rotary Motion Sensor (PS-2120A)
Mini-Rotational Accessory (CI-6691)	Mass and Hanger Set (ME-8979)
Base and Support Rod (ME-9355)	Triple Beam Balance (SE-8723)
Paper clips (for masses <1 g)	Calipers (SF-8711)

*Click the equipment item to go to the PASCO web site.

Purpose

The purpose of this experiment is to experimentally find the rotational inertia of a ring and a disk and verify that these values correspond to the calculated theoretical values.

Theory

Theoretically, the rotational inertia, I , of a ring about its center of mass is given by:

$$I = \frac{1}{2}M(R_1^2 + R_2^2)$$

where M is the mass of the ring, R_1 is the inner radius of the ring, and R_2 is the outer radius of the ring. See Figure 2.1.

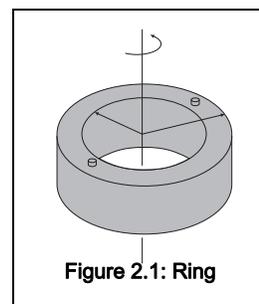


Figure 2.1: Ring

The rotational inertia of a disk about its center of mass is given by:

$$I = \frac{1}{2}MR^2$$

where M is the mass of the disk and R is the radius of the disk. See Figure 2.2. To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured, Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration, which is equal to a/r (a = acceleration), and τ is the torque caused by the weight hanging from the thread that is wrapped about the 3-step Pulley on the Rotary Motion Sensor. The torque is given by:

$$\tau = rT$$

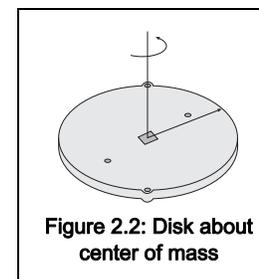


Figure 2.2: Disk about center of mass

where r is the radius of the pulley step about which the thread is wound, and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, m , gives:

$$\Sigma F = mg - T = ma$$

See Figure 2.3. Solving for the tension in the thread gives:

$$T = m(g - a)$$

Once the angular acceleration is measured, the radius and the linear acceleration, a , can be obtained for the calculation of the torque.

Setup

1. Mount the Rotary Motion Sensor (RMS) on a support rod and connect the sensor to the interface.
2. Mount the Super Pulley with Clamp to the end of the RMS.
3. Tie one end of a thread to a Mass Hanger and the other end of the thread to one of the levels of the 3-step Pulley on the RMS.
4. Drape the thread over the Super Pulley such that the thread is in the groove of the Super Pulley and the Mass Hanger hangs freely.
5. Adjust the Super Pulley with Clamp to an angle so that the thread runs in a line tangent to the point where it leaves the 3-step Pulley and is straight down the middle of the groove on the Super Pulley. See Figure 2.4.

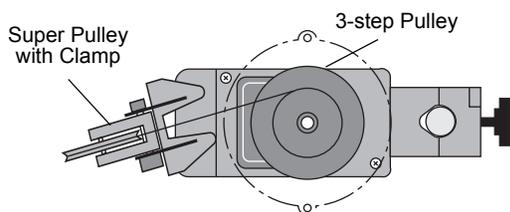


Figure 2.4: Super Pulley Position

6. Place the disk directly on the 3-step Pulley as shown in Figure 2.3.
7. Place the ring on the disk, inserting the ring pins on the bottom edge into the holes in the top of the disk as shown in figure 2.5.

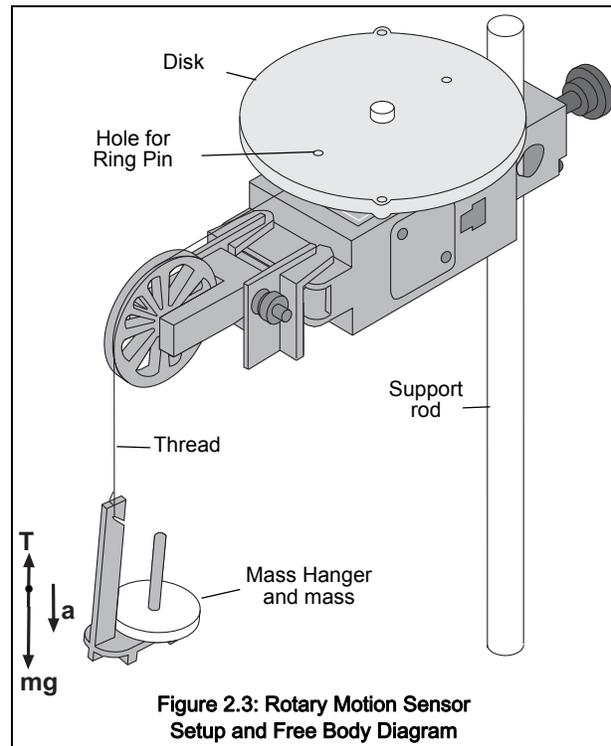


Figure 2.3: Rotary Motion Sensor Setup and Free Body Diagram

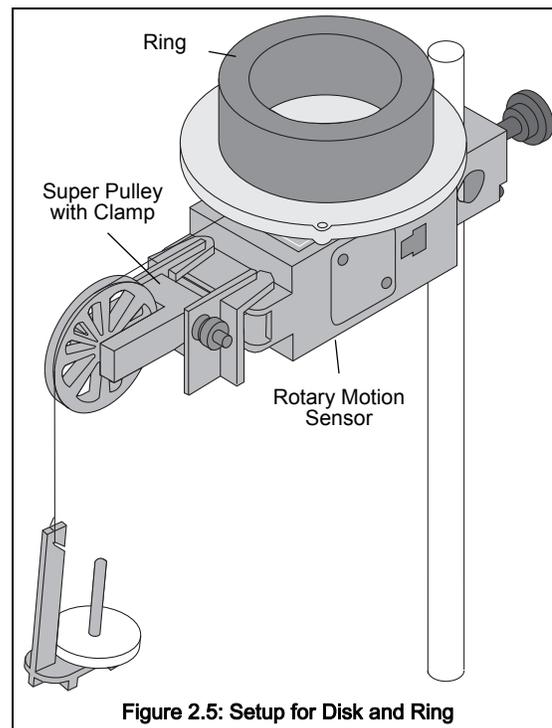


Figure 2.5: Setup for Disk and Ring

Procedure

Measurements for the Theoretical Rotational Inertia

1. Weigh the ring and the disk to find their masses and record these masses in Data Table 1.
2. Measure the inside and outside diameters of the ring and calculate the radii, R_1 and R_2 . Record in Data Table 1.
3. Measure the diameter of the disk and calculate the radius, R , and record into Data Table 1

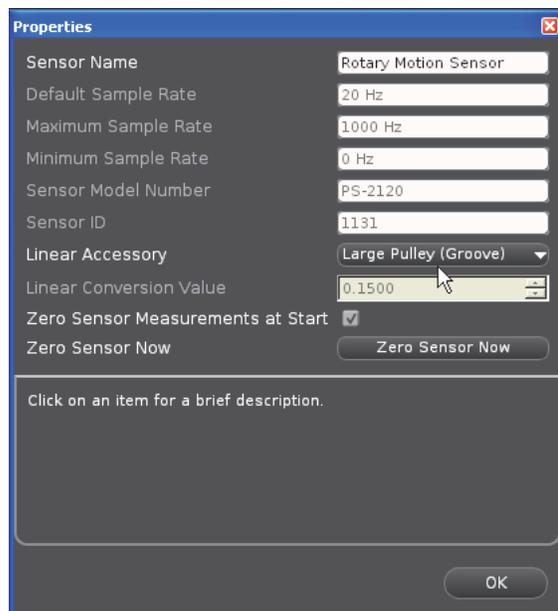
Data Table 1: Theoretical Rotational Inertia.

Mass of ring	
Mass of disk	
Inner radius of ring	
Outer radius of ring	
Radius of disk	

Measurements for the Experimental Method

A. Finding the Acceleration of the Ring and Disk

1. In the data collection software, create an experiment to measure the *angular velocity* (in radians per second) versus *time* (in second) of the ring and disk.
 - In PASCO Capstone, for example, drag the Graph icon from the Displays palette to the workbook. Select “Angular Velocity (rad/s)” for the vertical axis, and “Time (s)” for the horizontal axis.
 - Click the Hardware Setup icon in the Tools palette to open the “Hardware Setup” panel. In the panel, click the properties button (it looks like a gear wheel in the lower right corner).
 - In the Properties window for Linear Accessory, select the size of the 3-step Pulley you are using. The default setting is “Large Pulley (Groove)”. Click OK.
2. Put a 50-g mass on the Mass Hanger and turn the 3-step Pulley to wind up the thread so the hanger is just below the Super Pulley. Hold the 3-step Pulley.
3. Click **Record** to begin recording data, and release the 3-step Pulley, allowing the hanger to fall.
4. Caution! Click **Stop** to end data recording BEFORE the hanger reaches the floor or the thread completely unwinds from the 3-step Pulley.
5. In the Graph display, select the region of the data that represents when the ring and disk were accelerating.



Select Size of 3-step Pulley

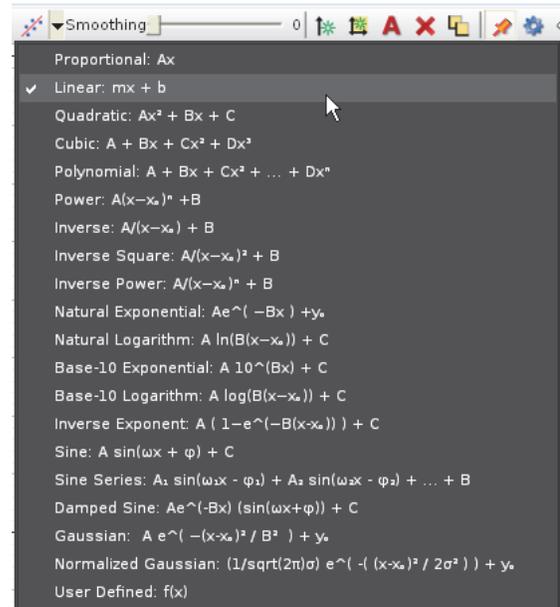
6. In the Graph display, select “Linear” from the curve fit menu.

The slope, m , of the linear fit represents the angular acceleration (α) for the Point Mass and Apparatus

7. Record the value of the slope, m , as the angular acceleration in Data Table 2.

B. Measure the Radius

- Using calipers, measure the diameter of the pulley about which the thread is wrapped and calculate the radius. Record the radius in Data Table 2.



Select “Linear” from the Curve Fit Menu

Data Table 2: Experimental Rotational Inertia Data

	Ring and Disk Combined	Disk Alone
Hanging Mass		
Slope, m		
Radius		

C. Finding the Acceleration of the Disk Alone

- In "Finding the Acceleration of Ring and Disk," both the disk and the ring are rotating; therefore, it is necessary to determine the acceleration and the rotational inertia of the disk by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the ring.
- Take the ring off the apparatus and repeat the steps under “Finding the Acceleration of the Ring and Disk” for the disk alone. Record the results in Data Table 2.

Calculations

- Calculate the experimental value of the rotational inertia of the ring and disk together, and record the value in Data Table 3.
- Calculate the experimental value of the rotational inertia of the disk alone and record the value in Data Table 3.
- Subtract the rotational inertia of the disk from the total rotational inertia of the ring and disk, and record this as the rotational inertia of the ring alone.
- Use a percent difference to compare the experimental values to the theoretical values.

Data Table 3: Results

Item	Rotational Inertia

Ring and Disk	
Disk alone	
Ring alone	
Percent difference for the disk	
Percent difference for the ring	

Experiment 3: Conservation of Angular Momentum

Equipment Required*	Equipment Required*
PASPORT-Compatible Interface	Rotary Motion Sensor (PS-2120A)
Mini-Rotational Accessory (CI-6691)	Mass and Hanger Set (ME-8979)
Base and Support Rod (ME-9355)	Triple Beam Balance (SE-8723)
Paper clips (for masses <1 g)	Calipers (SF-8711)

*Click the equipment item to go to the PASCO web site.

Purpose

A non-rotating ring is dropped onto a rotating disk, and the final angular speed of the system is compared with the value predicted using the principle of the conservation of angular momentum.

Theory

When the ring is dropped onto the rotating disk, there is no net torque on the system since the torque on the ring is equal and opposite to the torque on the disk. Therefore, there is no change in angular momentum; angular momentum (L) is conserved.

$$L = I_i\omega_i = I_f\omega_f$$

where I_i is the initial rotational inertia and ω_i is the initial angular speed of the disk and I_f is the final rotational inertia and ω_f is the final angular speed of the disk and the ring together.

The rotational inertia of a disk is given as:

$$I_i = \frac{1}{2}M_1R^2$$

and the final rotational inertia of a disk and ring together is:

$$I_f = \frac{1}{2}M_1R^2 + \frac{1}{2}M_2(r_1^2 + r_2^2)$$

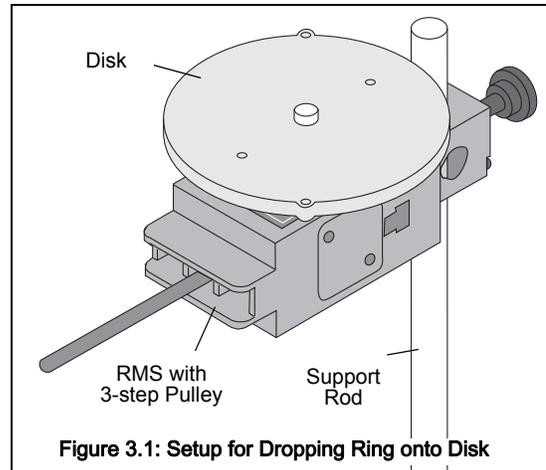
where M_1 is the mass of the disk, M_2 is the mass of the ring, R is the radius of the disk, and r_1 and r_2 are the inner and outer radii of the ring.

Based on this, the final rotational speed is given by:

$$\omega_f = \frac{M_1R^2}{M_1R^2 + M_2(r_1^2 + r_2^2)}\omega_i$$

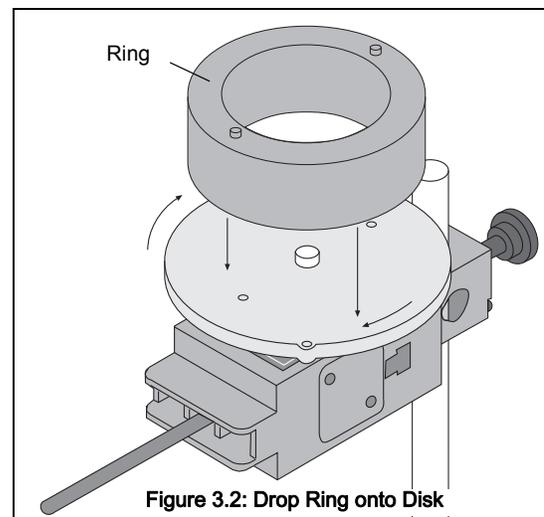
Setup

1. Mount the Rotary Motion Sensor to a support rod and connect it to the interface. Place the disk directly on the pulley as shown in Figure 3.1.
2. In the data collection software, create an experiment to measure the *angular velocity* (in radians per second) versus *time* (in second) of the disk before and after the ring is dropped on top of it.
 - In PASCO Capstone, for example, drag the Graph icon from the Displays palette to the workbook. Select “Angular Velocity (rad/s)” for the vertical axis, and “Time (s)” for the horizontal axis.



Procedure

1. Hold the ring with the pins facing up just above the center of the disk.
2. Give the disk a spin with your hand and click **Record** to begin recording data.
3. After about 25 data points have been recorded, drop the ring on the spinning disk. See Figure 3.2.
4. Click **Stop** to end data recording after the disk and ring have made a few rotations..
5. In the Graph display, select the region of the data that represents when the ring was dropped onto the disk.
6. In the Graph display, select the data analysis tool that shows the coordinates of any point in the plot of data and move the cursor to the data point that is immediately before the collision. Record the Angular Velocity at this point as the initial angular velocity in Data Table 1.
7. Move the cursor to the data point immediately after the collision. Record the Angular Velocity at this point as the final angular velocity in Data Table 1.
8. Weigh the ring and disk and record their masses. Measure the inner and outer radii of the ring, and the radius of the disk. Record these values in Data Table 1.



Analysis

1. Calculate the theoretical value for the final angular velocity and record this value in the Data Table.
2. Calculate the percent difference between the experimental and theoretical values of the final angular velocity and record it in the Data Table.

Questions

1. How does the experimental result for the final angular velocity compare with the theoretical value for the final angular velocity?

2. What percentage of the rotational kinetic energy was “lost” during the collision? Calculate the energy lost and record the results in the Data Table.

$$\% \text{ KE lost} = \left(\frac{\frac{1}{2}I_i\omega_i^2 + \frac{1}{2}I_f\omega_f^2}{\frac{1}{2}I_i^2\omega_i^2} \right)$$

.Data Table 1: Data and Results

Initial angular velocity	
Final angular velocity (experimental value)	
Mass of disk (M1)	
Mass of ring (M2)	
Inner radius of ring (r1)	
Outer radius of ring (r2)	
Radius of disk (R)	
Final angular velocity (theoretical value)	
Percent difference between experimental and theoretical values	
Percent of kinetic energy lost	