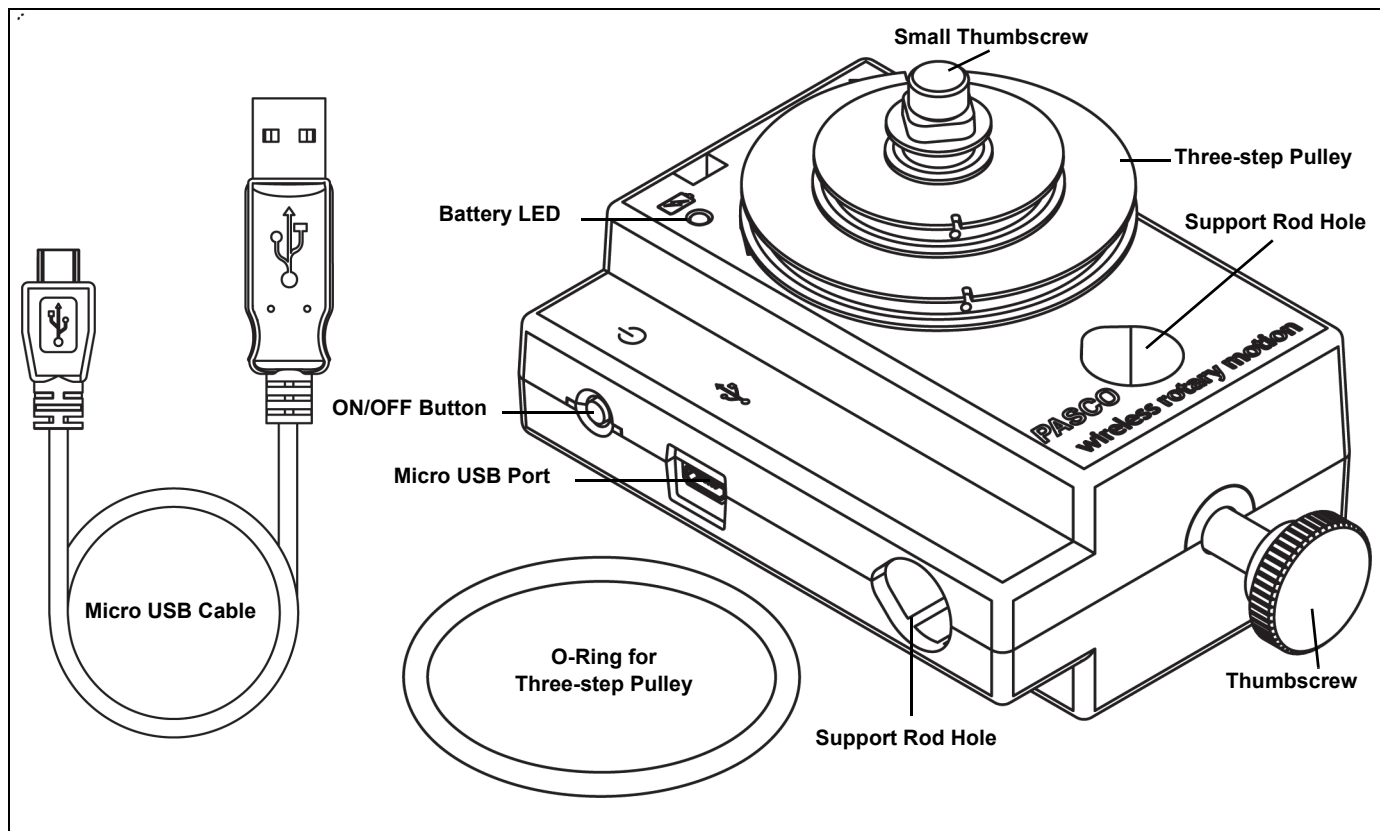


## Wireless Rotary Motion Sensor

PS-3220



Equipment Included	Equipment Included
Wireless Rotary Motion Sensor	Three-step Pulley
O-ring	Small Thumbscrew
Micro USB Cable (1 meter)	Thumbscrew

Required Item*	Part Number
PASCO Data Collection Software: Capstone or SPARKvue	see <a href="http://www.pasco.com">www.pasco.com</a>

\*See the PASCO catalog or the PASCO web site for more information.

[www.pasco.com](http://www.pasco.com)

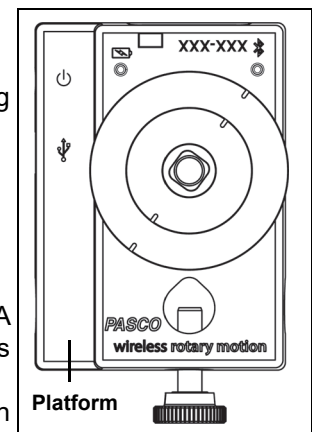
For downloadable experiments, go to [www.pasco.com](http://www.pasco.com) and enter PS-3220 in the Search window. Check under Resources.

Equipment used with the sensor	Equipment used with the sensor
Rotational Inertia Accessory Kit (ME-3420) (includes Ring and Disk Set (ME-3419), Pendulum Accessory (ME-8969), and Super Pulley with Clamp (ME-9444B))	
Physical Pendulum Set (ME-9633)	Track String Adapter (ME-6569)
Rotating Platform (ME-8951)	Centripetal Force Pendulum (ME-9821)
Gyroscope Mounting Bracket (ME-8963)	Polarization Analyzer (OS-8533A)
Dynamics Track Mount Accessory (CI-6692)	Three-Axis Gyroscope (ME-8960)
Three-Step Pulley Accessory (CI-6693)	

## Introduction

The PASCO Wireless Rotary Motion Sensor is a versatile position and motion measuring device. It measures angles to a resolution of  $0.18^\circ$ , and detects the direction of motion. Markings on the outside of the case indicate which is the default positive direction. The maximum speed is between 20 and 80 revolutions per second.

The sensor comes with a removable three-step pulley (10 millimeter (mm), 29 mm, and 48 mm diameters), and a rubber “O”-ring that fits into the largest diameter step. The three-step pulley can be placed large-diameter down or large-diameter up on the shaft. A tab on the inside of the pulley matches a notch on the outside of the shaft. The pulley has a notch and a small hole in the outer edge of the largest and second largest steps for attaching a string. One side of the sensor has a platform for mounting a Super Pulley with Table Clamp (optional).



## Using the Sensor

The sensor is designed to work with PASCO data collection software to measure position, velocity, and acceleration. Use it to study optics, dynamics, centripetal force, or motion of a pendulum.

## Data Collection Software

### PASCO Capstone



- Mac OS X
- Windows

### SPARKvue



- Mac OS X
- Windows
- iOS
- Android
- Chromebook

See the PASCO web site at

[www.pasco.com/software](http://www.pasco.com/software)

for help in selecting the right PASCO software and to check for the latest versions.

## 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**.

## Bluetooth<sup>®</sup> Compatibility

For more information about wireless compatibility, see the PASCO website at:

[www.pasco.com/compatibility](http://www.pasco.com/compatibility)

Platform	Bluetooth SMART Compatibility
iOS	iPad 3 and later iPhone 4S and later iPod touch 5 and later
SPARK LX / LXi	All models
Android	Android 4.4 and later
Chromebook	Chrome OS (requires PS-3500 Adapter*)
Mac OS X	Models introduced July 2011 or later*
Windows	Windows 7 and later (requires PS-3500 Adapter*)

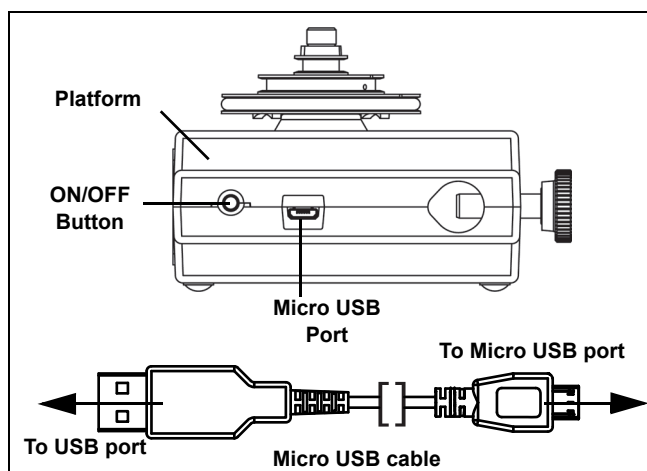
See Appendix B for more information about the PS-3500 Adapter and Mac OS X models.

## Initial Step: Charge the Battery

- **Connect the Cable:** Use the Micro USB Cable to connect the micro USB port on the side of the sensor to a USB **port** or USB **charger** such as the PASCO PS-2575 USB Single Port Charger. Charging begins automatically. The charger circuit inside the sensor turns itself off when the unit is fully charged. The battery status LED will shine yellow as the battery is charging, and will shine green when the battery is charged. The battery is partially charged at the factory. Initial charging time may be three hours or longer depending on the power source and the condition of the battery.

## ON/OFF Information

To turn the sensor on, press the ON button. The status LEDs will blink. To turn the sensor off, press and **hold** the ON button for a moment until the status LEDs stop blinking. The sensor puts itself to sleep after one hour of inactivity if connected, and after several minutes if not connected.



## LED Information

The Bluetooth and the Battery Status LEDs operate as follows:

### For a wireless Bluetooth connection:

Bluetooth LED	Status
Red blink	Ready to pair
Green blink	Connected
Yellow blink	Logging*

Battery LED	Status
Red blink	Low power

### For a micro USB cable connection to a USB port:

Bluetooth LED	Status
OFF	--
OFF	--
Yellow blink	Logging*

Battery LED	Status
Yellow ON	Charging
Green ON	Charged

### For a micro USB cable connection to a USB charger:

Bluetooth LED	Status
Red blink	Ready to pair
Green blink	Connected
Yellow blink	Logging*

Battery LED	Status
Yellow ON	Charging
Green ON	Charged

\***Logging:** PASCO wireless sensors can either stream live data to a compatible device or log data (save it to the sensor's memory). The data can then be uploaded to the device for display and analysis at a later time. Logging capability supports long-term or remote data collection while not connected to the device.

Note: The latest versions of SPARKvue and PASCO Capstone support logging. Check the PASCO Web page at:

[www.pasco.com/software](http://www.pasco.com/software)

for the latest software version.

## Set Up the Software

### SPARKvue

#### Connecting the Sensor to a Tablet or a Computer via Bluetooth

- For SPARKvue, select the Bluetooth icon. In the **Wireless Devices** list. The sensors are ordered by proximity to the device. Select the correct address that matches the Device ID XXX-XXX number found on the sensor. Select **Done**.

#### Connecting the Sensor to a Computer with the Micro USB Cable

- Connect the micro end of the included Micro USB Cable into the micro USB port on the side of the sensor. Connect the other end of the Micro USB Cable to a USB port on the computer, or into a powered USB hub connected to the computer.
- In the SPARKvue Home Screen, select a measurement from the list under the sensor's name. A graph of the measurement versus time opens.

### Collecting Data

- Select the Start button to begin collecting data.

## PASCO Capstone

### Connecting the Sensor to a Tablet or a Computer via Bluetooth

- For PASCO Capstone, select **Hardware Setup** in the Tools palette. In **Hardware Setup** the sensors are ordered by proximity to the device. Select the address that matches the Device ID XXX-XXX number on the sensor.

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.

### Connecting the Sensor to a Computer with the Micro USB Cable

- Connect the micro end of the included Micro USB Cable into the micro USB port on the end of the sensor. Connect the other end of the Micro USB Cable to a USB port on the computer, or into a powered USB hub connected to the computer.
- In PASCO Capstone, select a display in the main window or from the **Displays** palette. In the display, use the **<Select Measurement>** menus to pick the measurement to be shown.

### Collecting Data

- Select **Record** to begin recording data.

### Troubleshooting the Sensor

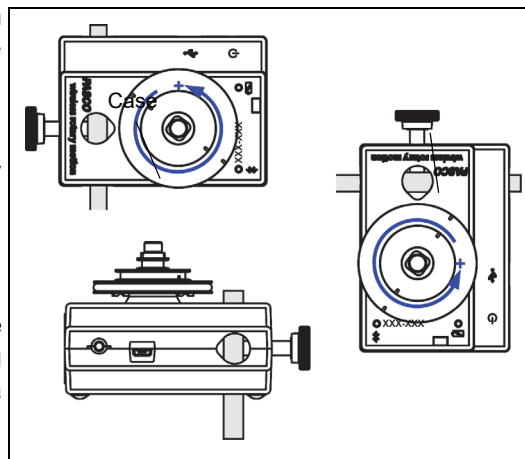
- If the sensor loses Bluetooth connection and will not reconnect, try cycling the ON button. Press and briefly **hold** the button until the status LEDs blink in sequence, and then release the button. Start the sensor in the usual way.
- If the sensor stops communicating with the computer software or tablet application, try restarting the software or application. If the problem remains, press and **hold** the ON button for 10 seconds and then release. Start the sensor in the usual way.
- Turn Bluetooth off and then back on. Retry.

## Mounting the Wireless Rotary Motion Sensor

The sensor case has two support rod holes that fit rods up to 12.7 mm in diameter, such as the ME-8736 45 cm Stainless Steel Rod, and the case can be put on the support rod using either of the support rod holes.

It is possible to mount the Wireless Rotary Motion Sensor horizontally on a support rod with the Three-step Pulley facing up or facing sideways. You can mount the sensor vertically with the pulley facing forward.

When mounted on a track as shown, a Rotary Motion Sensor could be used to measure the motion of a PASCO Cart as it is pulled by a string suspended over the Three-step Pulley of the sensor and attached to a hanging mass.



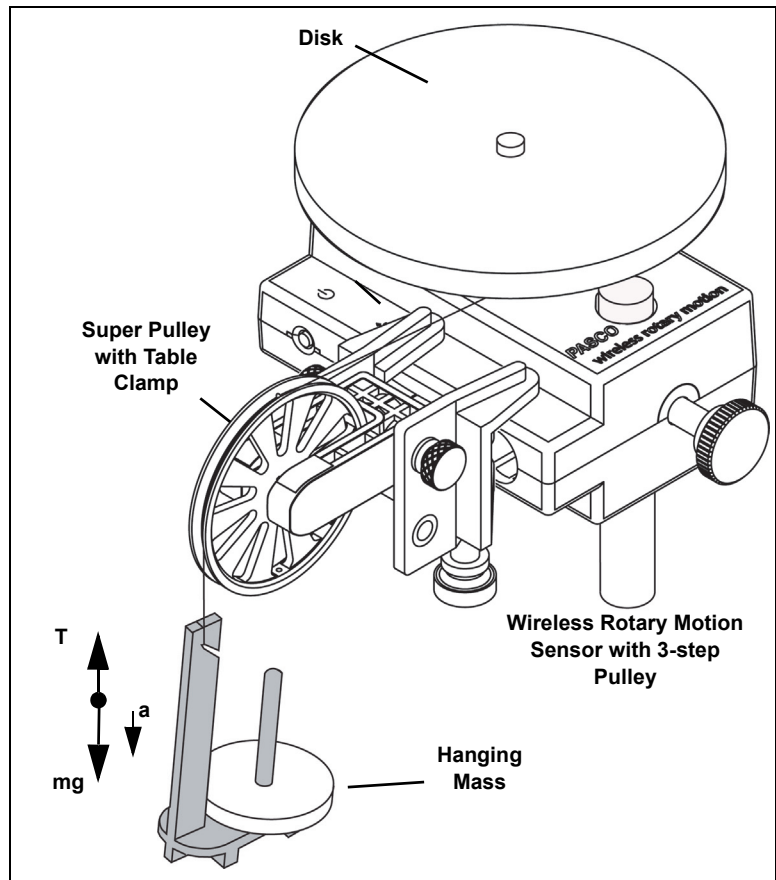
## Attaching Accessories to the Wireless Rotary Motion Sensor

### Using the Disk from the Disk and Ring Set (ME-3419)

For rotational inertia experiments, mount the Wireless Rotary Motion Sensor with the Disk horizontal. The underside of the Disk has a square shaped indent that fits the square-shaped top of the 3-Step Pulley. Mount a Super Pulley with Clamp (ME-9448B) on the platform at the side of the sensor. To provide a known torque, wrap a string around one of the steps of the 3-step Pulley. Arrange the end of the string over the Super Pulley and attach a hanging mass.

Adjust the Super Pulley on the platform so that the string is tangent to the step on the 3-step Pulley on the sensor.

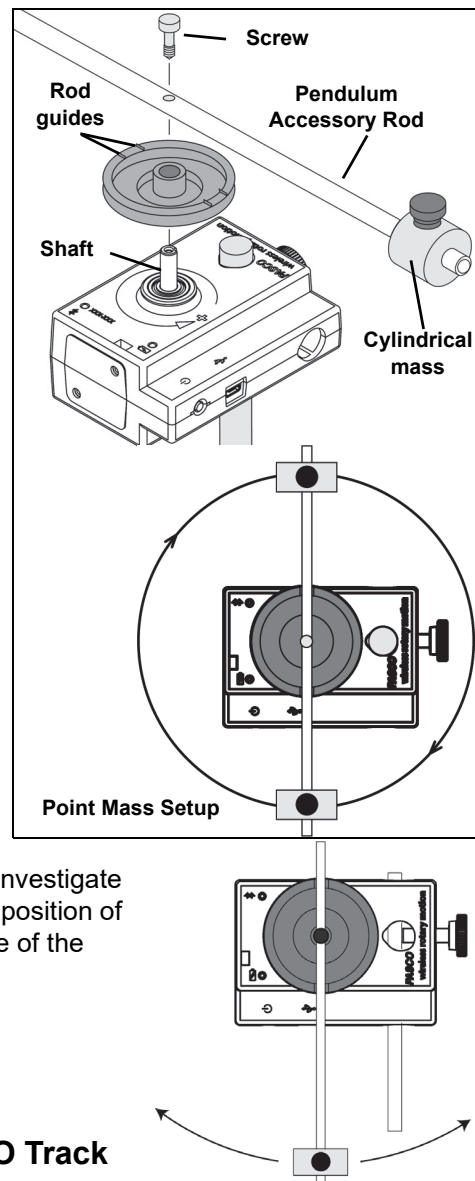
Perform a conservation of angular momentum experiment by dropping a second Disk onto the first Disk as it is rotating. Alternately, attach one of the Ring Alignment Devices to the first Disk and then drop the Ring onto the first disk. (See the suggested experiments.)



### Attaching the Pendulum Accessory Rod (part of ME-8969 Pendulum Accessory) to the Wireless Rotary Motion Sensor

To mount the rod of the Pendulum Accessory to the Wireless Rotary Motion Sensor, orient the 3-step Pulley so that the large diameter step is away from the sensor case. The large diameter step has two pair of rod guides opposite each other on the top edge. Align the rod with the rod guides and use the captive screw in the center of the rod to attach the rod and pulley onto the sensor's shaft.

**Point Mass Setup** Attach the center of the rod to the 3-step Pulley and shaft and mount the cylindrical masses at the ends of the rod to investigate the rotational inertia (moment of inertia) of point masses.



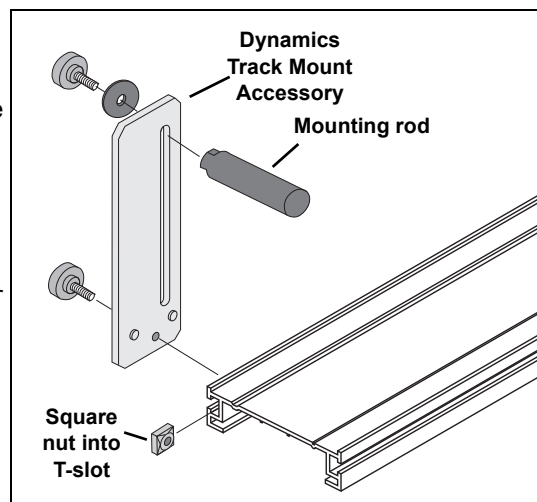
**Pendulum Setup** Attach the end of the rod to the 3-step Pulley and shaft. Mount a cylindrical mass on the rod to use the rod as a pendulum. Investigate the period of oscillation of the pendulum when the amount of mass or the position of the mass is changed. Investigate the period of oscillation as the amplitude of the swing is changed.

### Mounting the Wireless Rotary Motion Sensor on a PASCO Track

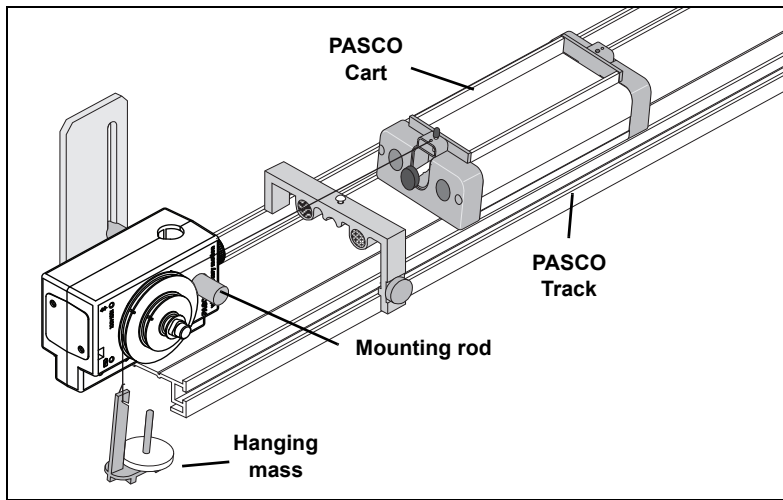
The sensor can also be mounted on the short rod that is part of the Dynamics Track Mount Accessory (CI-6692).

Slide the square nut of the Dynamics Track Mount Accessory into the T-slot on the side of the track. Adjust the position of the mounting rod on the Dynamics Track Mount Accessory.

When mounted on the track as shown, the Wireless Rotary Motion Sensor could be used to measure the motion of a PASCO Cart as it is pulled by a string suspended over the Three-step Pulley of sensor and attached to a mass hanger.





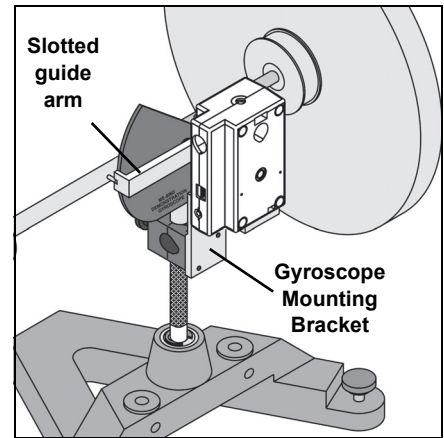


See the PASCO web site at [www.pasco.com](http://www.pasco.com) for more information.

### Mounting the Wireless Rotary Motion Sensor to a Gyroscope

Use the Gyroscope Mounting Bracket (ME-8963, available separately) to mount the Wireless Rotary Motion Sensor to the Three-Axis Gyroscope (ME-8960). Remove the gyroscope assembly from the vertical shaft of the large “A” base. Mount the Gyroscope Mounting Bracket onto the vertical shaft. Remove the three-step pulley from the Wireless Rotary Motion Sensor, and mount the sensor on the Gyroscope Mounting Bracket with the thumbscrews included with the bracket. Mount the slotted guide arm onto the shaft of the Wireless Rotary Motion Sensor. Replace the gyroscope assembly on the vertical shaft.

See the PASCO web site at [www.pasco.com](http://www.pasco.com) for more information.



## Experiments

Experiments for the Wireless Rotary Motion Sensor in electronic format are available to download from the PASCO web site.

[www.pasco.com](http://www.pasco.com)

Go to the web site, enter PS-3220 in the Search window, and check under Resources.

Three suggested experiments are:

- Rotational Inertia of a Point Mass
- Rotational Inertia of Disk and Ring
- Conservation of Angular Momentum.

### Specifications

Item:	Value
Three-step Pulley	10, 29 and 48 mm diameter
Sensor Dimensions	9 cm by 6.5 cm by 4 cm, 6.35 mm diameter shaft
Resolution	$\pm 0.09^\circ$ or 0.0078 mm 0.02 mm (linear) and $0.09^\circ$ (angular) at 2,000 points per revolution



Item:	Value
<b>Rotational Resolution</b>	0.00157 radian
<b>Maximum Rotation Rate</b>	30 rotations per second
<b>Optical Encoder</b>	Bidirectional, indicates direction of motion, 4,000 divisions/rotation

## Technical Support

For assistance with any PASCO product, contact PASCO at:

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

Phone: +1 916-462-8384 (worldwide)  
877-373-0300 (U.S.)

Web: [www.pasco.com](http://www.pasco.com)

Email: [support@pasco.com](mailto:support@pasco.com)

Check the PASCO website for the latest version of the instruction manual.

[www.pasco.com/manuals](http://www.pasco.com/manuals)

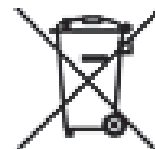
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### Product End of Life Disposal Instructions:

This electronic product is subject to disposal and recycling regulations that vary by country and region. It is your responsibility to recycle your electronic equipment per your local environmental laws and regulations to ensure that it will be recycled in a manner that protects human health and the environment. To find out where you can drop off your waste equipment for recycling, please contact your local waste recycle/disposal service, or the place where you purchased the product.

The European Union WEEE (Waste Electronic and Electrical Equipment) symbol (to the right) and on the product or its packaging indicates that this product **must not** be disposed of in a standard waste container.



## Appendix A: Bluetooth<sup>®</sup> SMART Compatibility

Check the PASCO Web page at

[www.pasco.com/compatibility](http://www.pasco.com/compatibility)

for the latest information on Bluetooth SMART compatibility.


Platform	Bluetooth SMART Compatibility
iOS	iPad 3 and later iPhone 4S and later iPod touch 5 and later
SPARK Element	All models
Android	Android 4.3 and later
Chromebook	Chrome OS (requires PS-3500 Adapter*)
Mac OS X <sup>1</sup>	Models introduced July 2011 or later
Windows 7 and 8	Requires PS-3500 Adapter*
Windows 10	Bluetooth SMART compatible

\*The PS-3500 USB Bluetooth 4.0 Adapter, when connected to a USB port, allows up to three Bluetooth SMART devices, such as this PASCO wireless device, to connect to Windows computers, Chromebooks, and older Macintosh computers.

Note: The PS-3500 USB Bluetooth 4.0 Adapter is the only adapter we can currently recommend. Many other Bluetooth 4.0 adapters are available but this adapter has a specific design that enables in-app pairing of Bluetooth SMART sensors.



<sup>1</sup>To check the Mac computer's Bluetooth compatibility, do the following:

- Click the  (Apple) Menu.
- Select *About This Mac*
- Click the *More Info...* button.
- Click the *System Report...* button.
- Select *Bluetooth* from the sidebar on the left, underneath *Hardware*.
- Scan down the list of information until you find "LMP Version".
- If your Mac is equipped with Bluetooth SMART, the LMP Version will show **0x6**. (Anything lower than **0x6** means an older version of Bluetooth. Your device will need the PS-3500 USB Bluetooth 4.0 Adapter.)

<sup>1</sup>The Mac Mini and MacBook Air were updated with Bluetooth SMART support in 2011. The MacBook Pro was updated in 2012. The Mac Pro that debuted in December 2013 has Bluetooth SMART support.

**Exception:** Before you upgrade to El Capitan (Mac OS X 10.11.x), if you have a Macintosh with LMP version "0x4" that requires the PS-3500 USB Bluetooth 4.0 Adapter, please contact PASCO Technical Support for further instructions.



## Experiment 1: Rotational Inertia of a Point Mass

### Equipment Required\*

Wireless Rotary Motion Sensor (PS-3220)  
 PASCO Data Collection Software  
 Rotational Inertia Accessory Kit (ME-3420)  
 Calipers (SF-8711)

### Equipment Required\*

Base and Support Rod (ME-9355)  
 Mass and Hanger Set (ME-8979)1  
 Triple Beam Balance (SE-8723)  
 Paper clips (for masses <1g)

\*See the PASCO Web site at [www.pasco.com](http://www.pasco.com) for more information

### 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  $\alpha$  is the angular acceleration, which is equal to  $a/r$  ( $a$  = linear acceleration), and  $\tau$  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

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

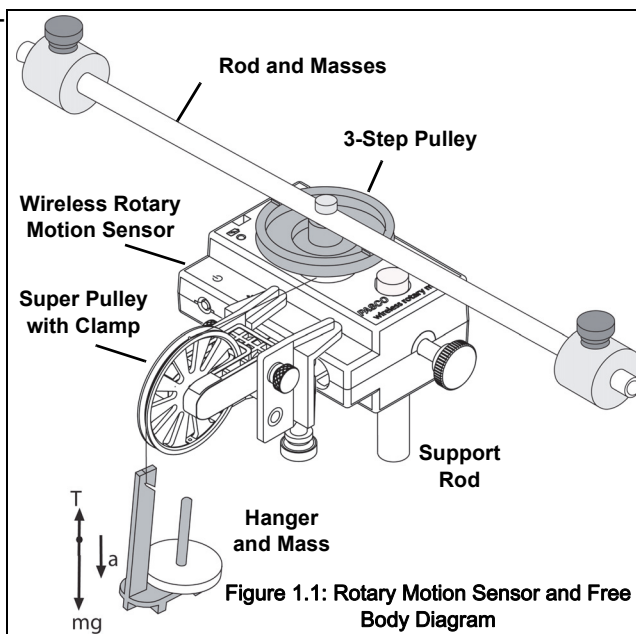
(see Figure 1.1). Solving for the tension in the thread gives:

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

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 Rotational Inertia I Accessory Kit) 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 Wireless Rotary Motion Sensor (WRMS).
3. Mount the rod and masses to the pulley on the Wireless Rotary Motion Sensor. Please note the orientation of the 3-step Pulley.
4. Mount the WRMS on a support rod. 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 (part of the ME-3420) on the platform of the Wireless 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.

7. Adjust the Super Pulley height so that the thread is level with the 3-step pulley.

## 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.
- 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 ( $a$ ) 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.



**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 Masses 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\*

Wireless Rotary Motion Sensor (PS-3220)  
 PASCO Data Collection Software  
 Rotational Inertia Accessory Kit (ME-3420)  
 Calipers (SF-8711)

### Equipment Required\*

Base and Support Rod (ME-9355)  
 Mass and Hanger Set (ME-8979)1  
 Triple Beam Balance (SE-8723)  
 Paper clips (for masses <1g)

\*See the PASCO Web site at [www.pasco.com](http://www.pasco.com) for more information

### 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.

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  $\alpha$  is the angular acceleration, which is equal to  $a/r$  ( $a$  = acceleration), and  $\tau$  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:

$$\tau = rT$$

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.

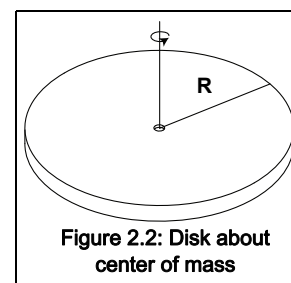
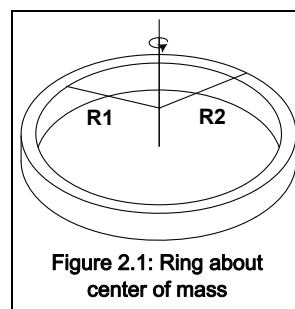
Applying Newton's Second Law for the hanging mass,  $m$ , gives:

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

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.



## 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	

## Setup

1. Mount the Wireless Rotary Motion Sensor (WRMS) on a support rod.
2. Mount the Super Pulley with Clamp on the side of the WRMS as shown in Figure 2.3.
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.
6. Remove the thumbscrew from the 3-Step Pulley. Place the disk directly on the square-shaped top of the 3-step Pulley as shown in Figure 2.3.
7. Place one of the disk alignment guides on the disk. Replace the thumbscrew to the 3-Step Pulley so that the disk alignment guide is firmly held in place.
8. Place the thin ring on the disk alignment guide on top of the disk as shown in figure 2.3..

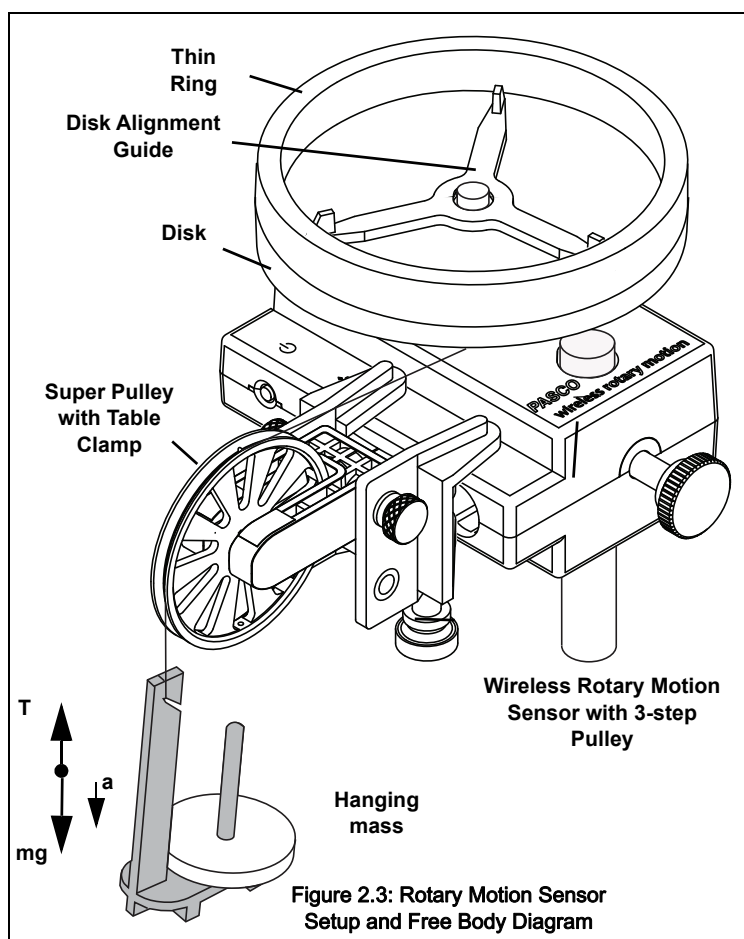


Figure 2.3: Rotary Motion Sensor Setup and Free Body Diagram

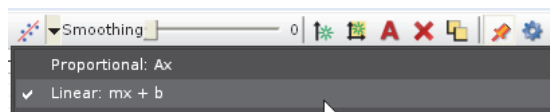
## Procedure

### Measurements for the Experimental Method

#### A. Finding the Acceleration of the Ring and Disk

- 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.
- 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.
- Click Record to begin recording data, and release the 3-step Pulley, allowing the hanger to fall.
- Caution! Click Stop to end data recording BEFORE the hanger reaches the floor or the thread completely unwinds from the 3-step Pulley.
- In the Graph display, select the region of the data that represents when the ring and disk were accelerating.
- In the Graph display, select “Linear” from the curve fit menu.

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



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

**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 3.

## Calculations

- Calculate the experimental value of the rotational inertia of the ring and disk together, and record the value in Data Table 3.

4. Calculate the experimental value of the rotational inertia of the disk alone and record the value in Data Table 3.
5. 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.
6. 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\*

Wireless Rotary Motion Sensor (PS-3220)  
 PASCO Data Collection Software  
 Mini-Rotational Accessory (CI-6691)  
 Calipers (SF-8711)

### Equipment Required\*

Base and Support Rod (ME-9355)  
 Mass and Hanger Set (ME-8979)1  
 Triple Beam Balance (SE-8723)  
 Paper clips (for masses <1g)

\*See the PASCO Web site at [www.pasco.com](http://www.pasco.com) for more information

### Purpose

A non-rotating thin 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  $\omega_i$  is the initial angular speed of the disk and  $I_f$  is the final rotational inertia and  $\omega_f$  is the final angular speed of the disk and the ring together.

The rotational inertia of a disk is given as:

$$I_i = \frac{1}{2} M_1 R^2$$

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

$$I_f = \frac{1}{2} M_1 R^2 + \frac{1}{2} M_2 (r_1^2 + r_2^2)$$

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:

$$\omega_f = \frac{M_1 R^2}{M_1 R^2 + M_2 (r_1^2 + r_2^2)} \omega_i$$

### Setup

1. Mount the Wireless Rotary Motion Sensor to a support rod. Remove the thumbscrew from the 3-Step Pulley. Place the disk directly on the square-shaped top of the 3-step Pulley as shown in Figure 3.1.
2. Place one of the disk alignment guides on the disk. Replace the thumbscrew to the 3-Step Pulley so that the disk alignment guide is firmly held in place.

3. 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

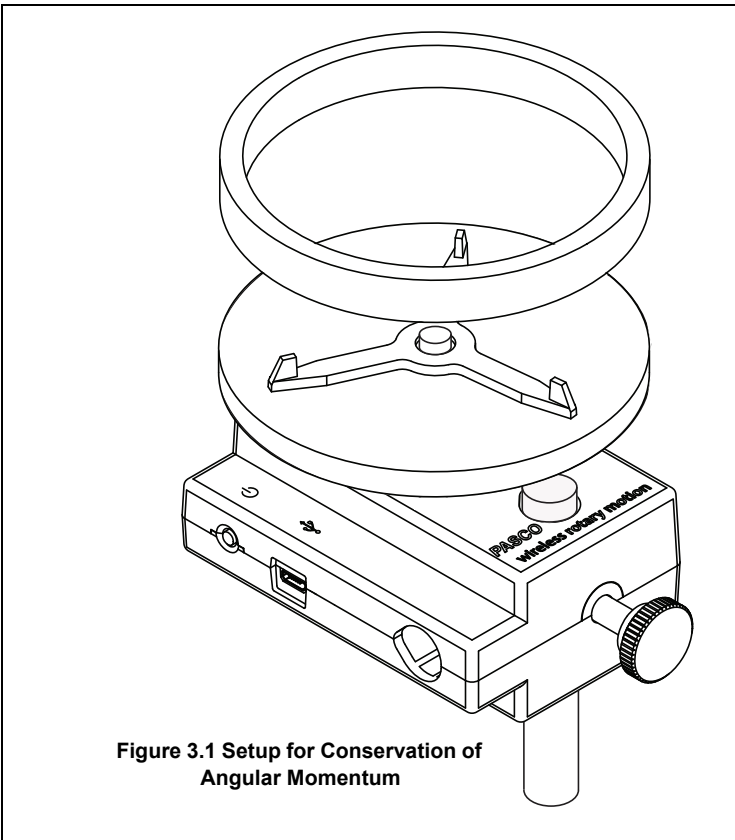
1. Hold the thin ring just above the disk alignment guide that is on the top of the disk.
  2. Give the disk a spin with your hand and click Record to begin recording data.
  3. After about 25 data points have been recorded, drop the thin ring onto the spinning disk. See Figure 3.1.
  4. Click Stop to 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 the Data Table.
  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 the Data Table.
  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 the Data Table.

Figure 3.1 Setup for Conservation of Angular Momentum

## 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: 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	