Instruction Manual and Experiment Guide for the PASCO scientific Model CI-6538

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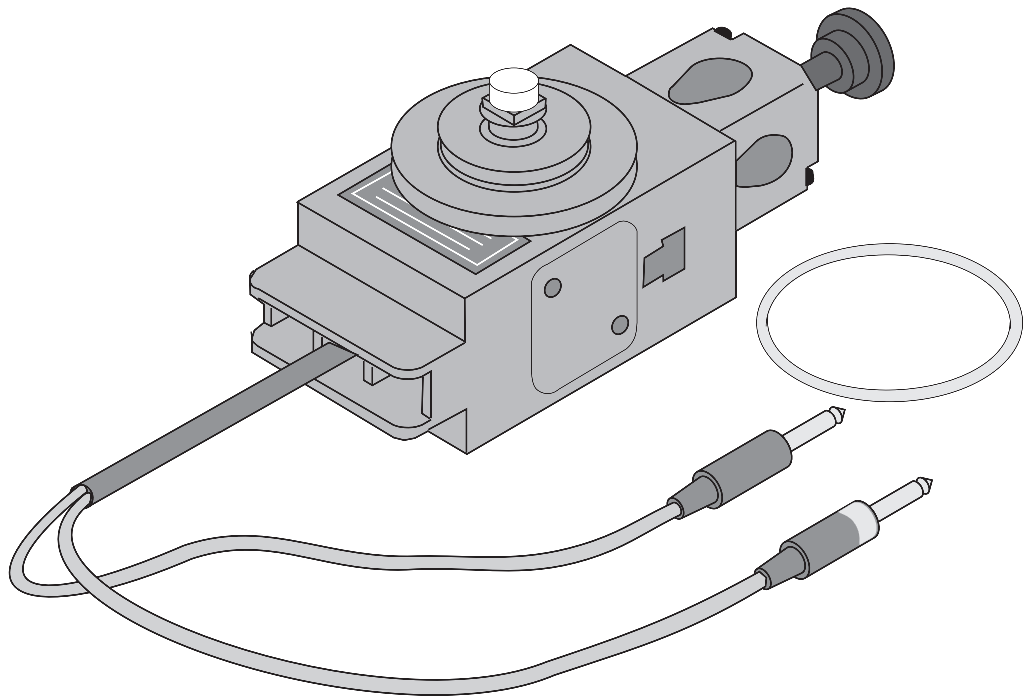
ROTARY MOTION SENSOR



$10.00

PASCO scientific

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This manual authored by: Jon Hanks

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➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION FROM PASCO.

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① The packing carton must be strong enough for the item shipped.

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③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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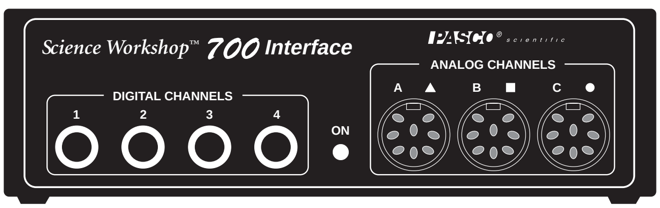
Introduction

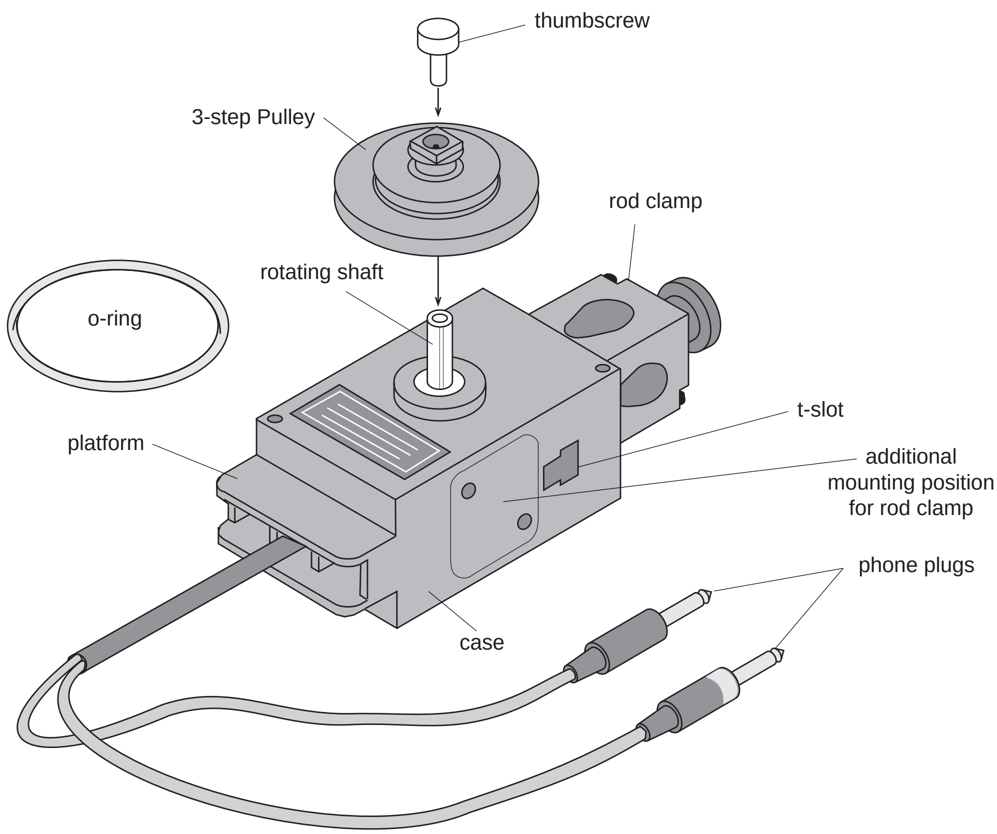
The PASCO CI-6538 Rotary Motion Sensor (RMS) is a bidirectional position sensor designed for use with the PASCO *Science Workshop™ 700 Interface*. It contains an optical encoder which gives a maximum of 1440 counts per revolution (360 degrees) of the Rotary Motion Sensor shaft. The resolution can be set in the *Science Workshop* software to 360 or 1440 times per revolution (1 degree or 1/4 degree). The direction of rotation is also sensed.

The Rotary Motion Sensor has two phone plugs which plug into any two adjacent digital channels on the 700 interface box.



Science Workshop version 2.1 or higher is required.

The rod clamp can be mounted on three sides of the sensor case, allowing the Rotary Motion Sensor to be mounted on a rod stand in many different orientations. The 3-step Pulley keys into the rotating shaft and can be mounted on either end of the shaft. A rubber o-ring is intended to be slipped over the largest pulley step so the RMS can be pressed against a surface to sense the relative motion between the sensor and the surface. The end of the Rotary Motion Sensor where the cord exits the case provides a platform for mounting a clamp-on Super Pulley. The t-slot in either side of the RMS is for inserting the optional Linear Motion Accessory rack. This allows you to measure linear motion over the length of the rack.

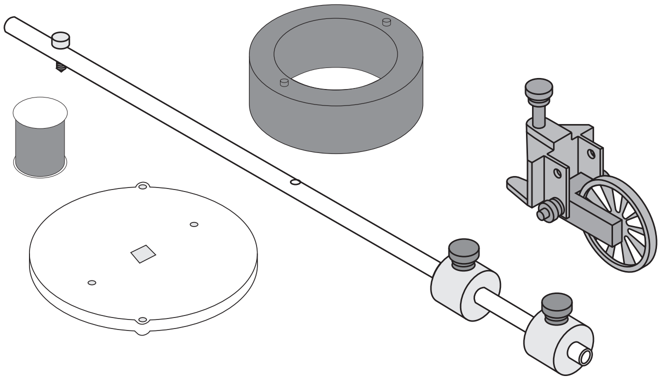


Rotary Motion Sensor Parts

Optional Accessories

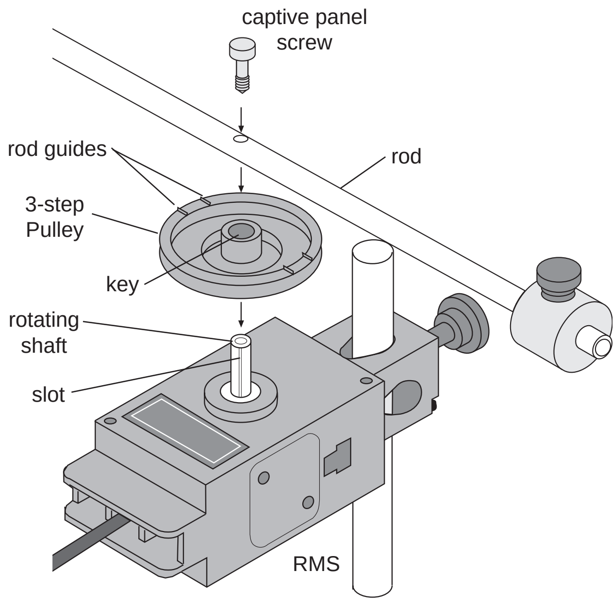
Mini-Rotational Accessory

The PASCO CI-6691 Mini-Rotational Accessory is used to perform rotational inertia experiments, conservation of angular momentum experiments, and pendulum experiments. Included are an aluminum disk, a steel ring, a long thin rod, and two brass masses which can be attached at any point on the thin rod to act as point masses.



Attaching the Rod

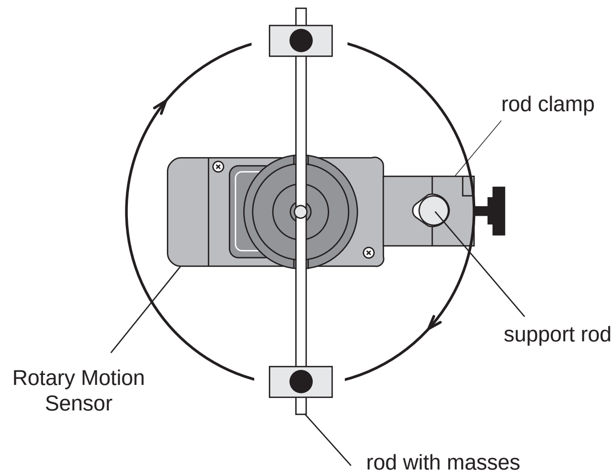
To attach the rod to the RMS, it is necessary to orient the 3-step Pulley so the rod guides on the underside of the pulley face up. The 3-step Pulley and the rotating shaft on the RMS are keyed to assemble only in one position. Assemble the apparatus as illustrated.



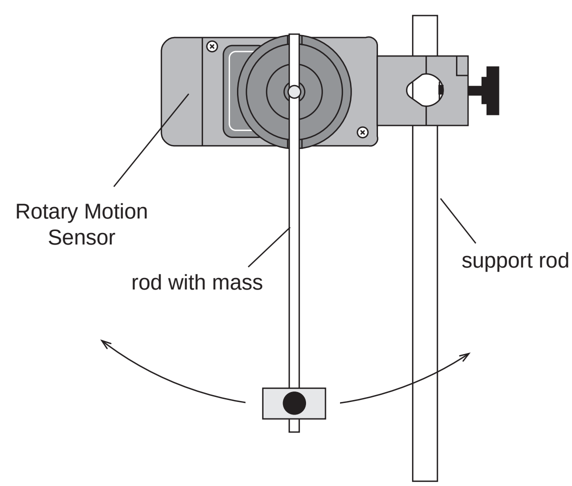
Using the Rod

The rod can be used for two purposes:

- The center of the rod can be attached to the RMS rotating shaft and used with the point masses to find the rotational inertia of point masses.



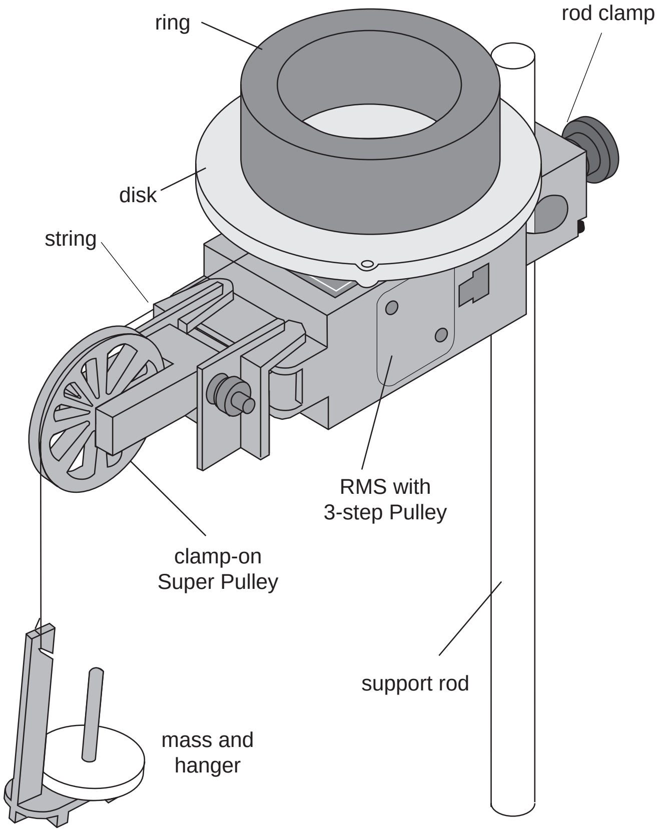
- The end of the rod can be attached to the Rotary Motion Sensor rotating shaft to use it as a pendulum.



Using the Disk and Ring

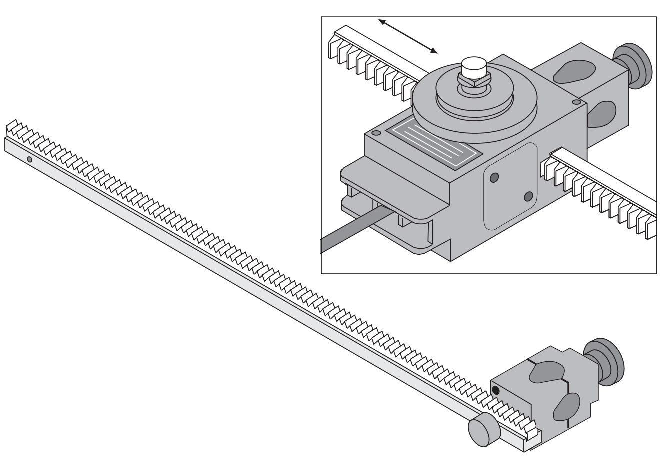
For rotational inertia experiments, wrap a string attached to a mass around the 3-step Pulley included with the Rotary Motion Sensor. Hang the mass over the clamp-on Super Pulley to accelerate the apparatus.

Perform a conservation of angular momentum experiment by dropping the ring onto the rotating disk.



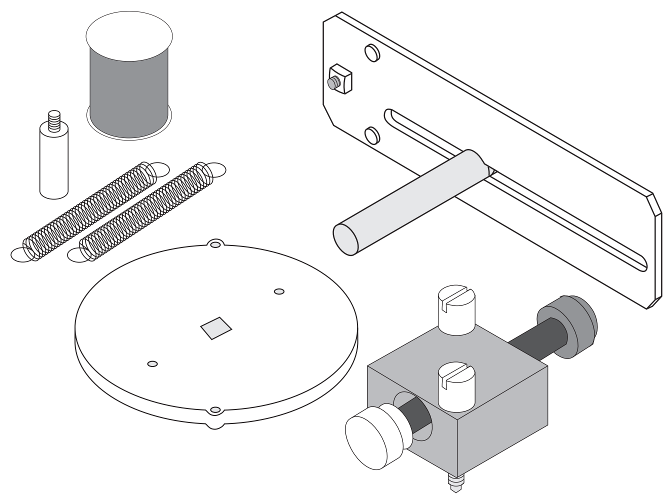
Linear Motion Accessory

The PASCO CI-6688 Linear Motion Accessory is a 21 cm long rack that is inserted into the t-slot in the side of the RMS to convert a linear motion into a rotary motion. The teeth on the rack engage a gear inside the RMS, causing it to rotate as the rack is pushed through the slot. The rack may be inserted into either side of the RMS. Sensors can be mounted to the rack using the rod clamp which can be attached to either end of the Linear Motion Accessory rack.

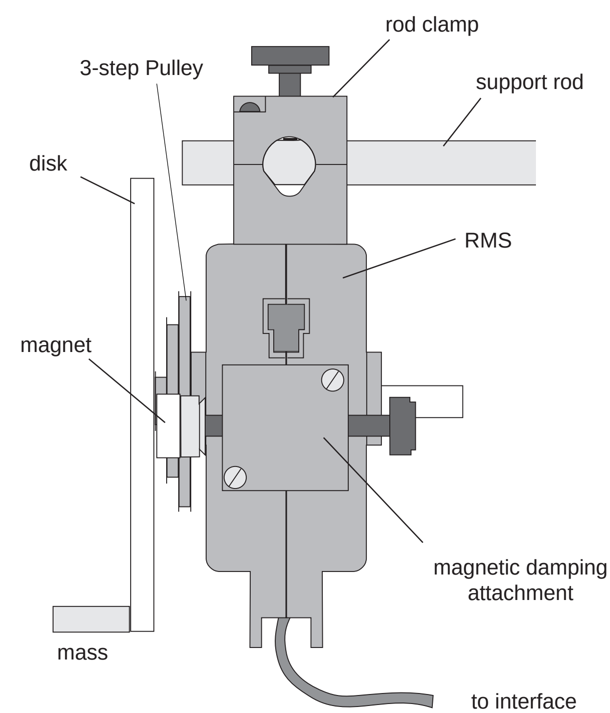


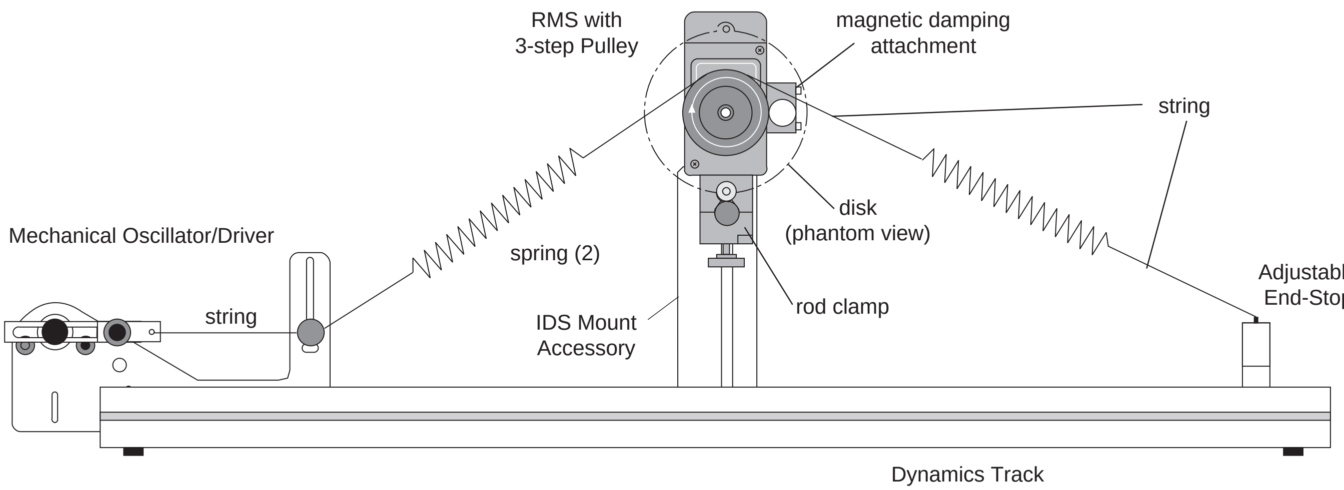
Chaos Accessory

The PASCO CI-6689 Chaos Accessory consists of an aluminum disk (identical to the one provided with the Mini-Rotational Accessory), a mass which attaches to the edge of the disk to form a physical pendulum, two springs for putting tension in the thread, a mounting bracket for mounting the RMS to the PASCO Introductory Dynamics System tracks (1.2 meter ME-9435A or 2.2 meter ME-9458), and an adjustable-gap magnet which attaches to the side of the RMS to provide variable magnetic damping. See the next page for diagram of the equipment setup.



The Chaos Accessory is a driven damped physical pendulum. Various types of phase plots can be made as the driving frequency, driving amplitude, initial conditions, and amount of damping are varied.

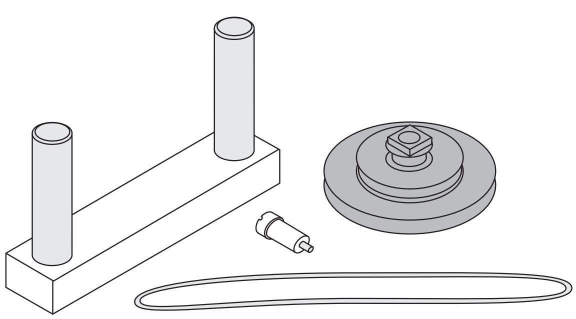




Chaos Accessory with Mechanical Oscillator on a Dynamics Track

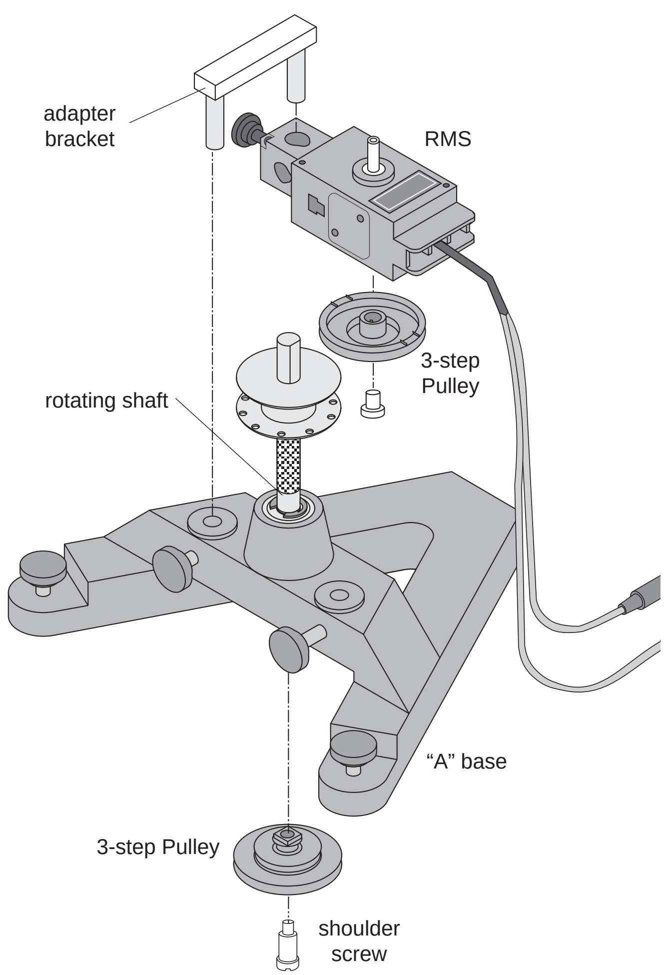
A PASCO ME-8750 Mechanical Oscillator/Driver is also required to drive the Chaos Accessory. The 1.2 m Dynamics Track is used as a convenient way to mount and align all the components. However, it is possible to mount the components on separate rod stands if a Dynamics Track is not available.

“A”-base Rotational Adapter

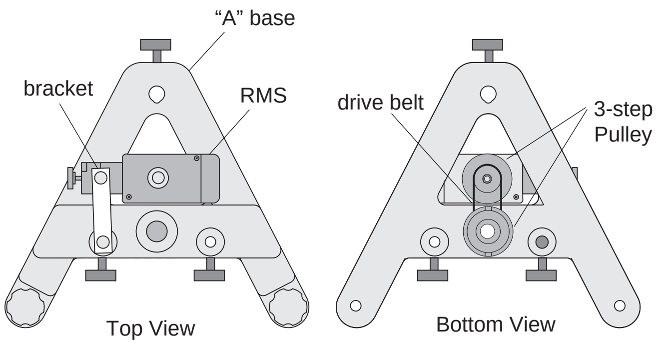


The CI-6690 “A”-base Rotational Adapter is used to mount the Rotary Motion Sensor to the “A” base of the ME-8951 Rotating Platform or the ME-8960 Gyroscope. The RMS provides higher resolution than a Smart Pulley, and precession of the Gyroscope can be plotted since the RMS keeps track of direction of rotation. The adapter includes a mounting bracket, a shoulder screw, a drive belt (o-ring), and a 3-step Pulley. The drive belt links the 3-step Pulley mounted on the “A” base to the 3-step Pulley on the RMS. For a one-to-one correspondence, connect the two pulleys using the o-ring on the middle step of each pulley. Each revolution of the Rotating Platform or Gyroscope corresponds to one revolution of the RMS. If desired, a 5-to-1 ration can be attained by putting the o-ring on the top or bottom steps.

The pulley attaches to the underside of the rotating shaft with the shoulder screw. Please note the pulley orientation illustrated below. The bracket connects to the “A” base of the Rotating Platform or the Gyroscope and to the RMS rod clamp.

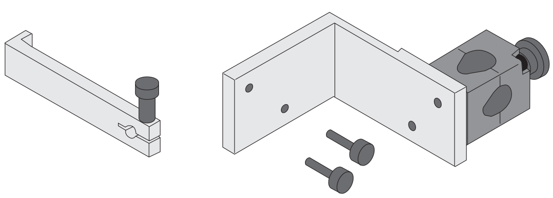


Assembling the RMS to the “A” Base

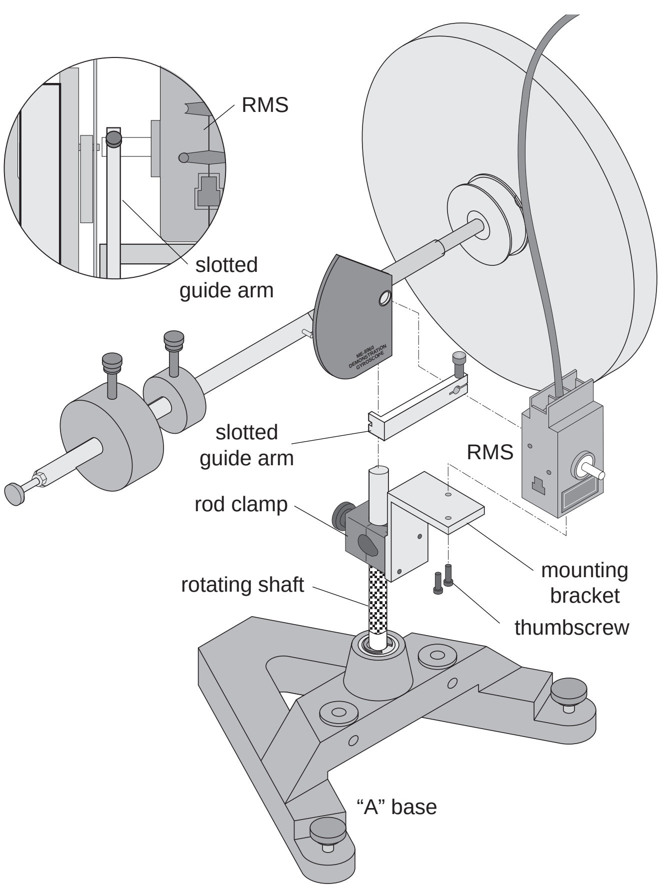


RMS Mounted on "A" Base

RMS/Gyroscope Mounting Bracket

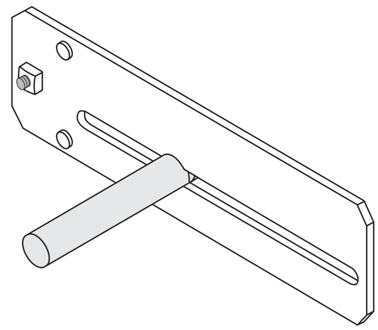


The PASCO ME-8963 RMS/Gyroscope Mounting Bracket attaches the Rotary Motion Sensor to the ME-8960 Gyroscope so the angle of nutation can be detected.

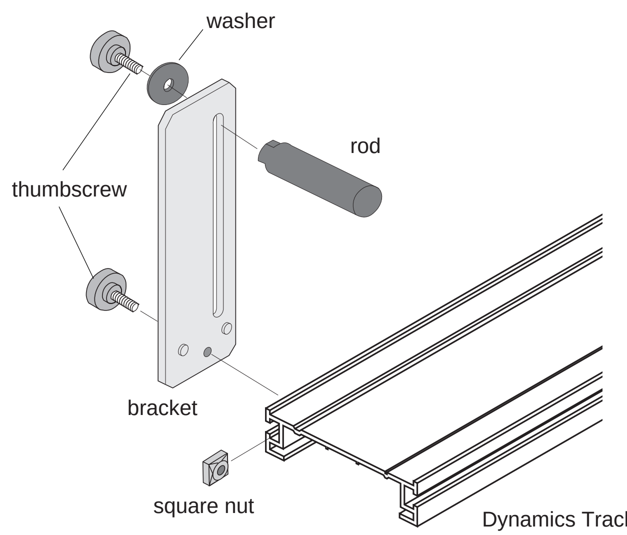


Assembling the RMS to the Gyroscope

IDS Mount Accessory

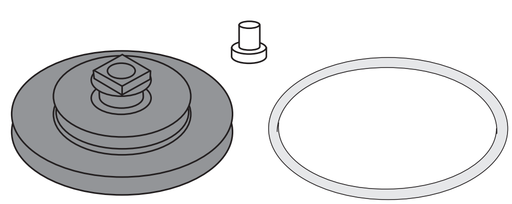


The PASCO CI-6692 IDS Mount Accessory is a bracket that allows the Rotary Motion Sensor to be easily attached to the Introductory Dynamics System tracks.



Attaching IDS Mount Accessory to Dynamics Track

3-step Pulley Accessory



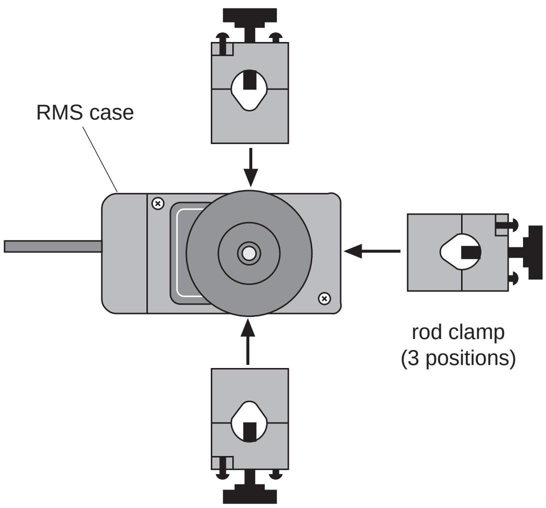
The PASCO CI-6693 3-step Pulley Accessory includes an additional pulley for mounting a 3-step Pulley on each end of the Rotary Motion Sensor rotating shaft. It also includes an o-ring.

General Setup and Operation

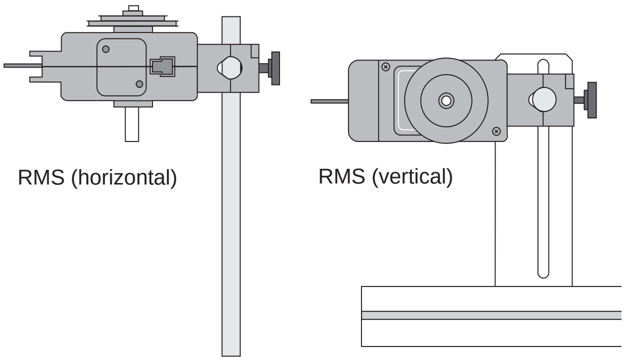
Mounting the RMS

Attaching the RMS to a Support Rod

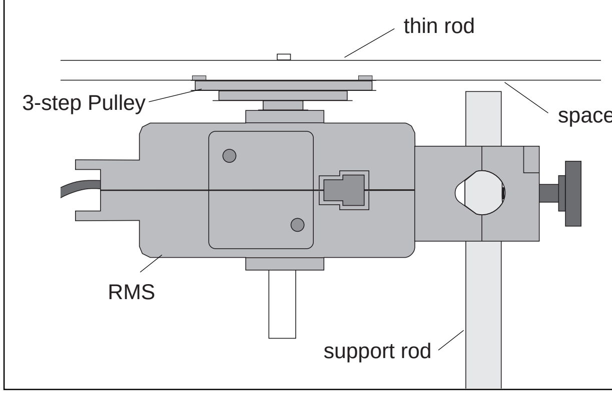
The Rotary Motion Sensor can be mounted on a support rod using the supplied rod clamp. The rod clamp can be mounted in three different locations on the Rotary Motion Sensor: at the end opposite the cable and on either side of the case. A Phillips screwdriver is required to remove the two screws that hold the rod clamp on the Rotary Motion Sensor case.



It is possible to mount the RMS horizontally on a support rod, with the 3-step Pulley facing up or vertically, with the pulley facing forward.

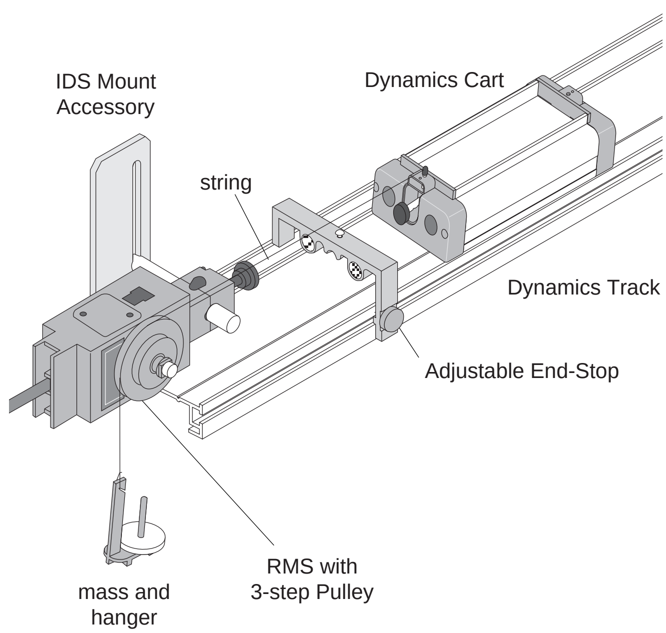


➤ **NOTE:** When setting up the rotational inertia experiment with the thin rod from the Mini-Rotational Accessory, the Rotary Motion Sensor must be mounted at the top of the support rod so the rod does not interfere with the rotation of the thin rod.



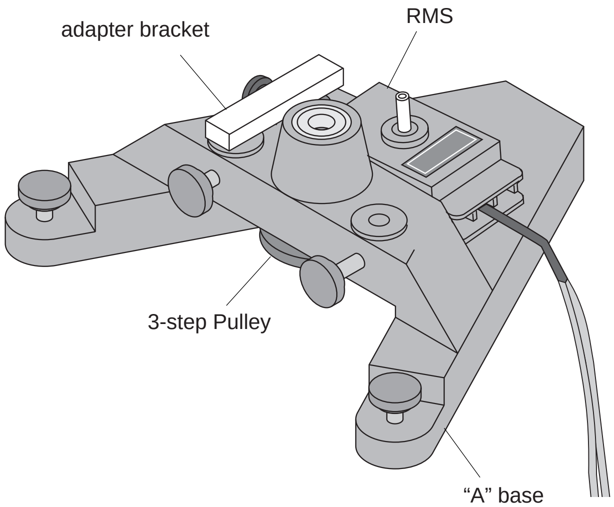
Attaching the RMS to a Dynamics Track

The Rotary Motion Sensor can be mounted to a Dynamics Track using the IDS Mount Accessory. The RMS mounts on the horizontal rod using the RMS rod clamp. The Rotary Motion Sensor can be used as a "Smart Pulley" in this configuration by threading a string over the Rotary Motion Sensor pulley and hanging a mass on the string.



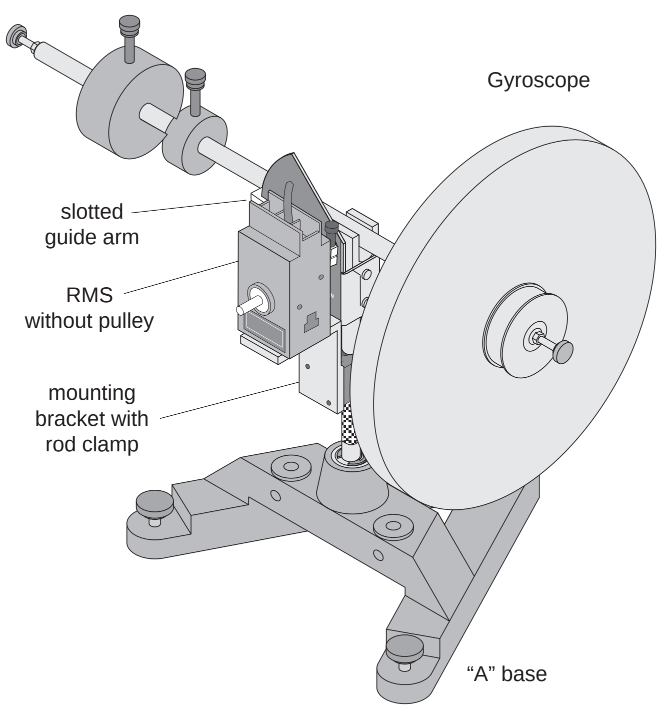
Attaching the RMS to the "A" base

The Rotary Motion Sensor can be mounted to the Rotating Platform or the Gyroscope using the "A"-base Rotational Adapter. This allows the precession angle of the Gyroscope to be detected.



Attaching the RMS to the Gyroscope

The Rotary Motion Sensor can be mounted to the Gyroscope using the RMS/Gyroscope Accessory. This allows the nutation angle of the Gyroscope to be detected.



Plugging the Rotary Motion Sensor Into The Interface

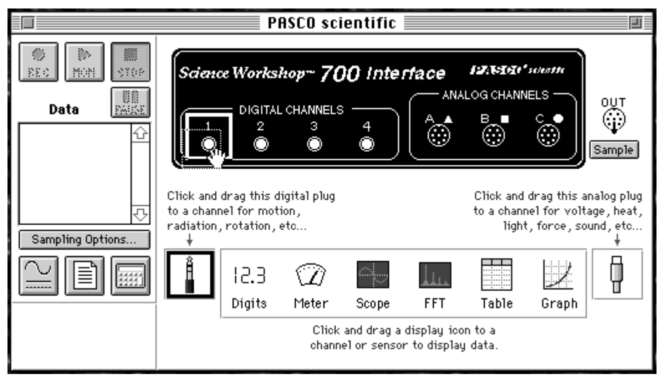
To operate the Rotary Motion Sensor, it must be plugged into the *Science Workshop™ 700 Interface*. The two phone plugs from the Rotary Motion Sensor need to be plugged into any two adjacent digital input channels on the 700 interface box. The order of the plugs is not critical.

> ➤ **NOTE:** If the direction of movement of the Rotary Motion Sensor produces a negative displacement when you desire a positive displacement, simply reverse the order of the plugs.

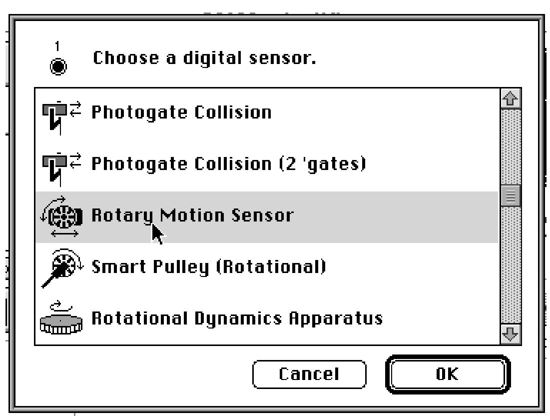
Using the *Science Workshop™* Software with the Rotary Motion Sensor

① Start *Science Workshop.*

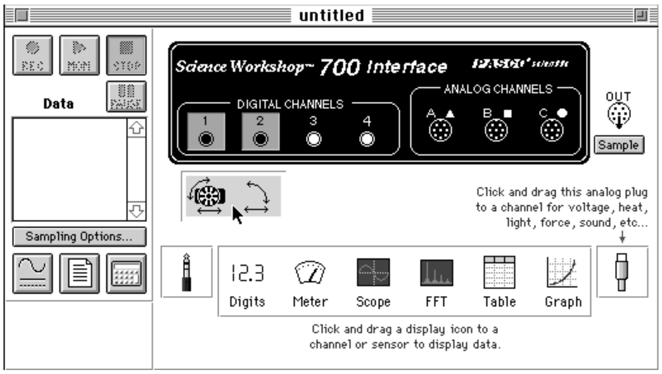
② On the Experiment Setup Window, click on the phone plug icon and drag it to one of the digital channels.



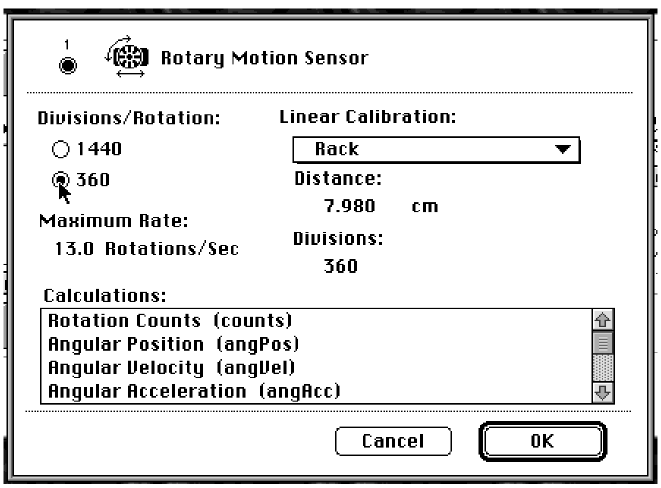
③ Select the Rotary Motion Sensor from the digital sensor menu and click on OK.



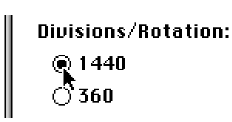
The program will automatically show two phone plugs plugged into two consecutive channels.



④ Double click on the Rotary Motion Sensor icon to activate the sensor setup dialog box for the Rotary Motion Sensor.

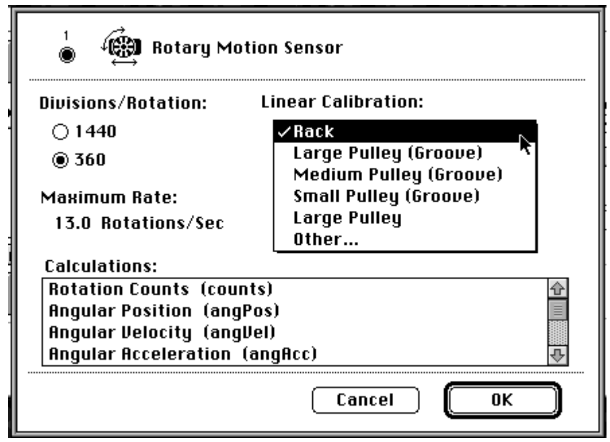


Choose the resolution: 360 divisions per rotation (the default value) or 1440 divisions per rotation.

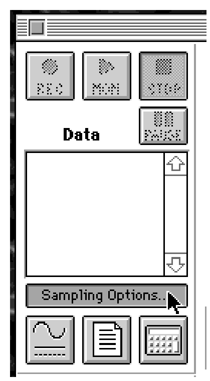


The required resolution depends on the rate at which the Rotary Motion Sensor will rotate during the experiment. See the *Suggested Experiments* section of this manual for suggested resolutions. In general, if the RMS will turn quickly during the experiment, the resolution should be 360 divisions per rotation so the data rate won't be too high. If the RMS will turn slowly and a finer resolution is needed, 1440 should be chosen.

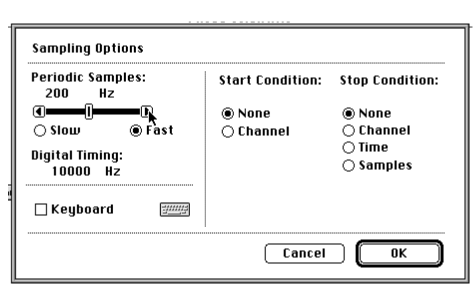
If the RMS is used to take linear measurements, it is necessary to choose the type of linear accessory used. Make the appropriate selection in the Linear Calibration section of the settings menu.



⑤ Click on "Sampling Options" and set the rate at which data will be sampled.



In general, the sampling rate should be as fast as possible. If the sampling rate is too fast, the lines in a graph become chunky.



Experiment 1: Rotational Inertia of a Point Mass

EQUIPMENT REQUIRED

– *Science Workshop™ 700 Interface*
– Mini-Rotational Accessory (CI-6691)
– Base and Support Rod (ME-9355)
– paper clips (for masses < 1 g)
– Rotary Motion Sensor (CI-6538)
– Mass and Hanger Set (ME-9348)
– Triple Beam Balance (SE-8723)
– calipers

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 $\tau = I\alpha$,

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

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:

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

Once 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.

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 the string to the Mass Hanger and the other end to one of the levels of the 3-step Pulley on the RMS.

③ Mount the thin rod to the pulley on the Rotary Motion Sensor. Please note the orientation of the 3-step Pulley.

④ Mount the RMS to a support rod and connect it to a computer. Make sure that the support rod does not interfere with the rotation of the accessory rod. See Figure 1.1.

⑤ Mount the clamp-on Super Pulley to the Rotary Motion Sensor.

⑥ Drape the string over the Super Pulley such that the string is in the groove of the pulley and the Mass Hanger hangs freely (see Figure 1.1).

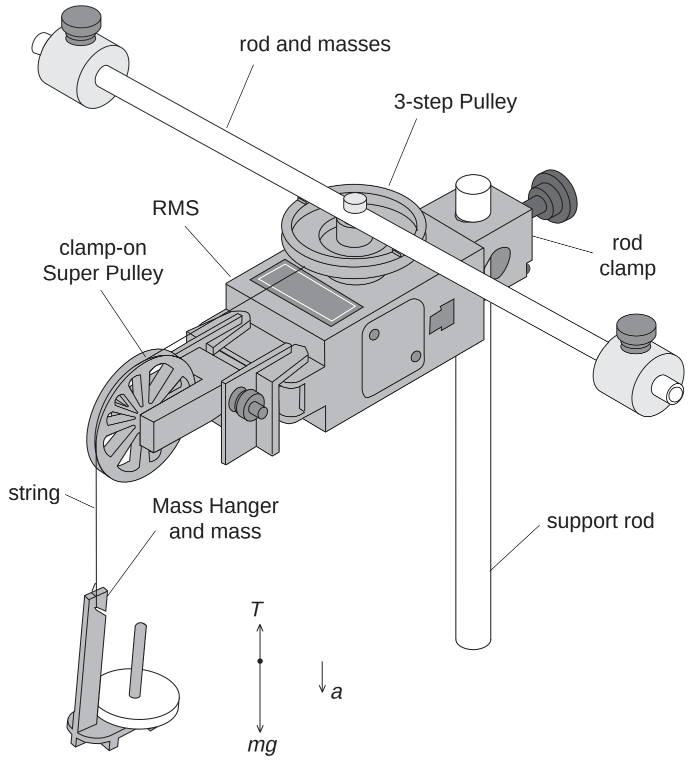
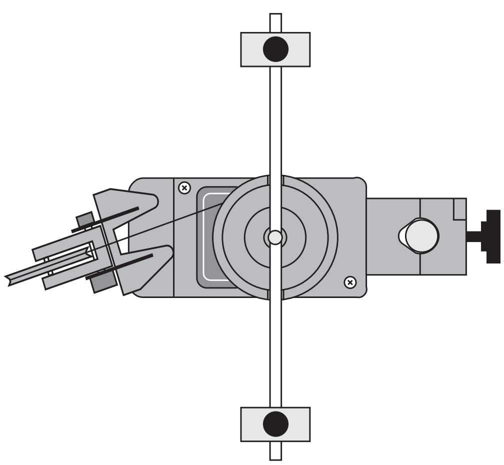


Figure 1.1: Rotary Motion Sensor and Free-Body Diagram

➤ **NOTE:** The clamp-on Super Pulley must be adjusted at an angle so 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 the thread is level with the 3-step Pulley.

Procedure

Part I: Measurements For the Theoretical Rotational Inertia

① Weigh the masses to find the total mass M_{total} and record in Table 1.1.

② Measure the distance from the axis of rotation to the center of the masses and record this radius in Table 1.1.

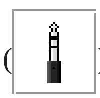
Table 1.1: Theoretical Rotational Inertia Data

Total Mass	
Radius	

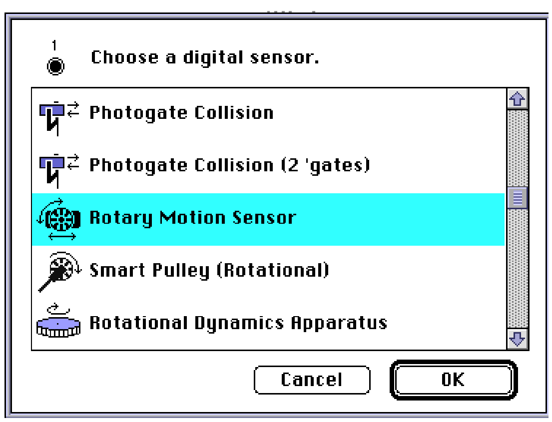
Part II: Measurement For the Experimental Method

Finding the Acceleration of the Point Masses and Apparatus

① Run *Science Workshop*.

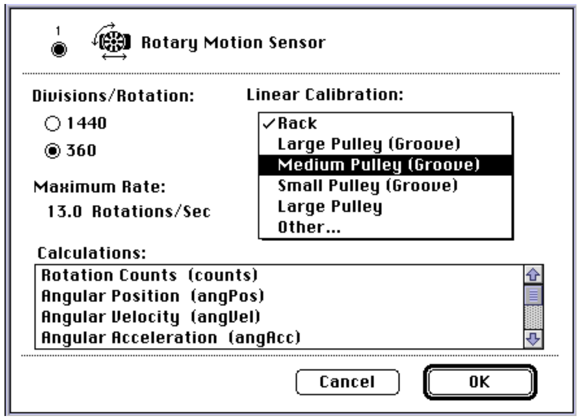
② In the Experiment Setup window, click and drag a digital sensor icon () to the first of the two consecutive digital ports that the RMS is plugged into.

③ Select the RMS from the digital sensor menu and click OK.

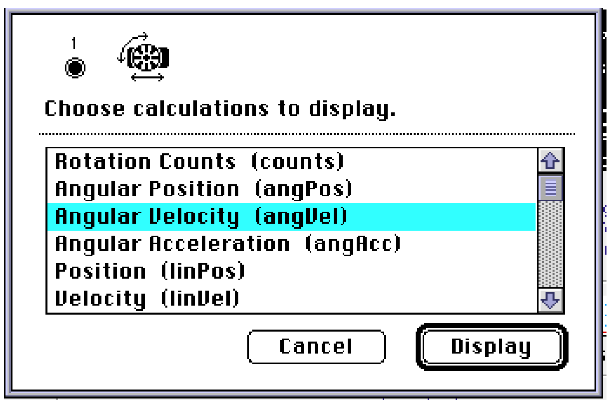


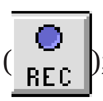
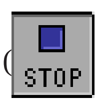
④ Double click the RMS icon in Experiment Setup window to activate the sensor dialog box for the RMS.

⑤ Ensure that the Divisions / Rotation radio button is in the 360 position, and select the appropriate pulley in the Linear Calibration pop-up menu; click OK.

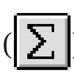


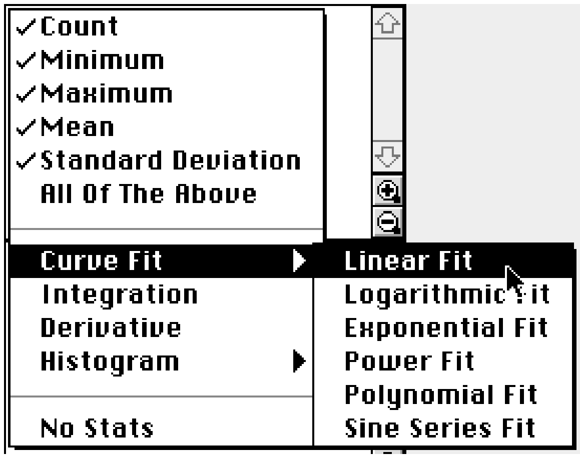
⑥ Click and drag a Graph to the RMS icon and select "Angular Velocity" from the built in calculations window; click OK.



⑦ Put the 50 g mass on the Mass Hanger and wind up the thread. Click on the Record button (
); then release the 3-step Pulley, allowing the mass to fall. Click the Stop button (
) to end the data collection.

➤ **HINT**: Click the stop button before the mass reaches the floor or the end of the thread to avoid erroneous data.

⑧ In the Graph Display window, click on the Statistics button (); then select the linear curve fit from the pop-up menu.



The slope of the linear fit represents the angular acceleration (α) and should be entered in Table 1.2.

Measure the Radius

① Using calipers, measure the diameter of the pulley about which the thread is wrapped and calculate the radius. Record in Table 1.2.

Finding the Acceleration of the Apparatus Alone

In **Finding the Acceleration of the Point Mass and Apparatus,** the apparatus is rotating and contributing to the rotational inertia. It is necessary to determine the acceleration and the rotational inertia of the apparatus by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the point masses.

① Take the point masses off the rod and repeat **Finding the Acceleration of the Point Mass and Apparatus** for the apparatus alone. It may be necessary to decrease the amount of the hanging mass so the apparatus does not accelerate so fast that the computer cannot keep up with the data collection rate.

② Record the data in Table 1.2.

Calculations

① Calculate the experimental value of the rotational inertia of the point masses and apparatus together and record in Table 1.3.

② Calculate the experimental value of the rotational inertia of the apparatus alone. Record in Table 1.3.

③ Subtract the rotational inertia of the apparatus from the combined rotational inertia of the point masses and apparatus. This will be the rotational inertia of the point masses alone. Record in Table 1.3.

④ Calculate the theoretical value of the rotational inertia of the point masses. Record in Table 1.3.

⑤ Use a percent difference to compare the experimental value to the theoretical value. Record in Table 1.3.

Table 1.2: Experimental Rotational Inertia Data

	Point Mass and Apparatus	Apparatus Alone
Hanging Mass		
Slope		
Radius		

Table 1.3: Results

Rotational Inertia for Point Masses and Apparatus Combined	
Rotational Inertia for Apparatus Alone	
Rotational Inertia for Point Masses (experimental value)	
Rotational Inertia for Point Masses (theoretical value)	
% Difference	

Experiment 2: Rotational Inertia of Disk and Ring

EQUIPMENT REQUIRED

– *Science Workshop™ 700 Interface*
– Mini-Rotational Accessory (CI-6691)
– Base and Support Rod (ME-9355)
– paper clips (for masses < 1 g)
– Rotary Motion Sensor (CI-6538)
– Mass and Hanger Set (ME-9348)
– Triple Beam Balance (SE-8723)
– calipers

Purpose

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

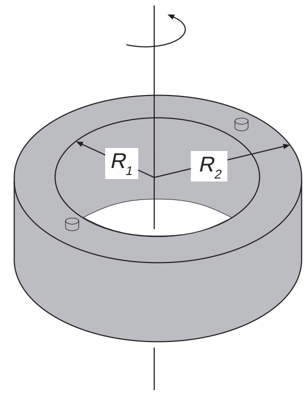


Figure 2.1: Ring

Theory

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

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

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:

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

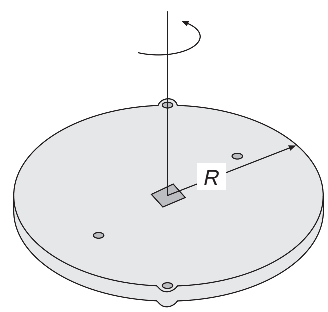


Figure 2.2: Disk about center of Mass

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 around the base of the apparatus.

$$\tau = rT$$

where r is the radius of the 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 2.3). Solving for the tension in the thread gives:

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

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

Setup

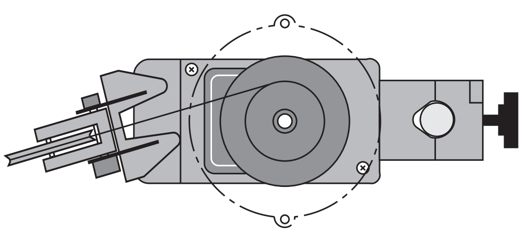
① Mount the RMS to a support rod and connect it to the interface.

② Mount the clamp-on Super Pulley to the Rotational Motion Sensor.

③ Tie one end of the string to the Mass Hanger and the other end to one of the levels of the 3-step Pulley on the RMS.

④ Drape the string over the Super Pulley such that the string is in the groove of the pulley and the Mass Hanger hangs freely (see Figure 2.3).

➤ **NOTE:** The clamp-on Super Pulley must be adjusted at an angle so 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.



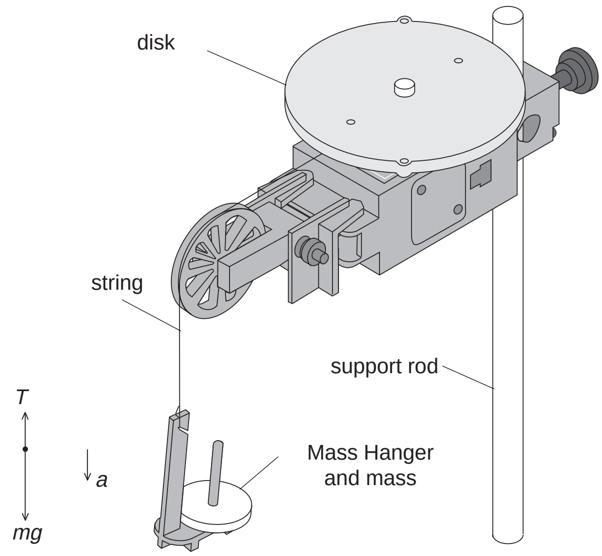


Figure 2.3: Rotary Motion Sensor and Free-Body Diagram

⑤ Place the disk directly on the pulley as shown in Figure 2.3.

⑥ Place the mass ring on the disk, inserting the ring pins into the holes in the disk as shown in Figure 2.4.

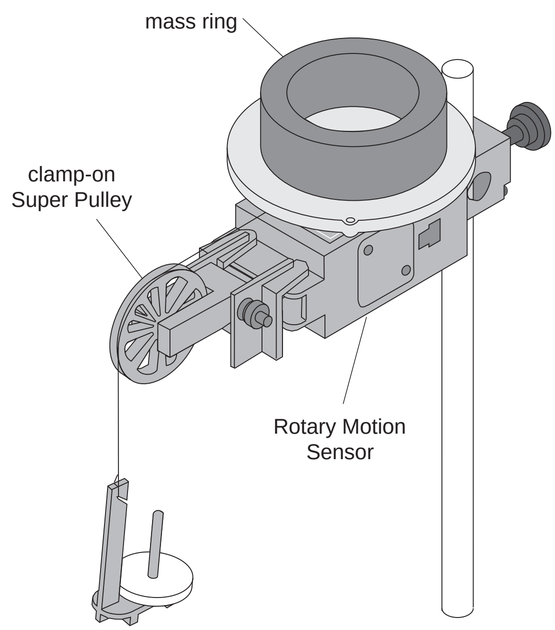


Figure 2.4: Setup for Disk and Ring

Procedure

Measurements for the Theoretical Rotational Inertia

① Weigh the ring and disk to find their masses and record these masses in Table 2.1.

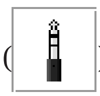
② Measure the inside and outside diameters of the ring and calculate the radii, R_1 and R_2. Record in Table 2.1.

③ Measure the diameter of the disk and calculate the radius, R, and record it in Table 2.1.

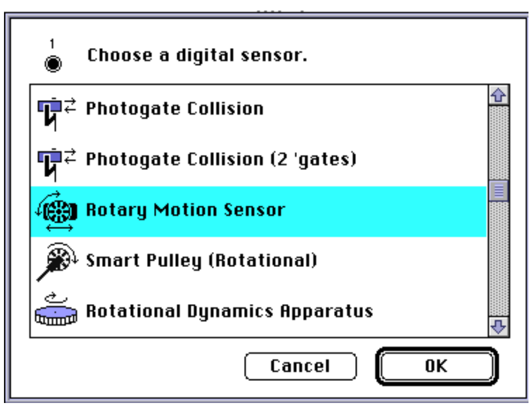
Measurements for the Experimental Method

Finding the Acceleration of Ring and Disk

① Run *Science Workshop*.

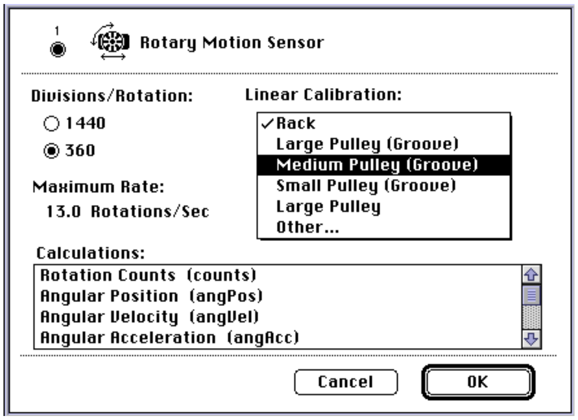
② In the Experiment Setup window, click and drag a digital sensor icon () to the first of the two consecutive digital ports that the RMS is plugged into.

③ Select the RMS from the digital sensor menu and click OK.

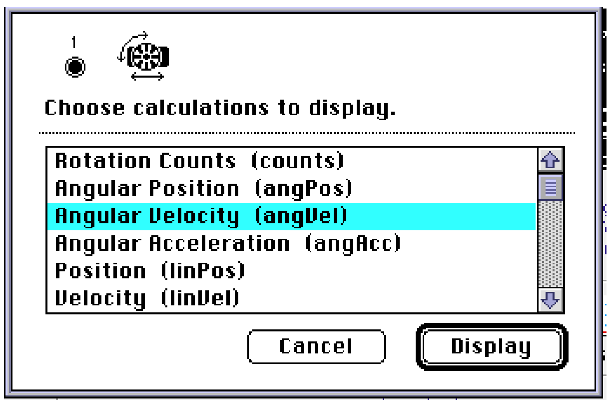


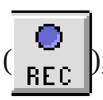
④ Double click the RMS icon in Experiment Setup window to activate the sensor dialog box for the RMS.

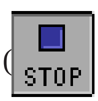
⑤ Ensure that the Divisions / Rotation radio button is in the 360 position, and select the appropriate pulley in the Linear Calibration pop-up menu; click OK.



⑥ Click and drag a Graph to the RMS icon and select “Angular Velocity” from the built-in calculations window; click OK.

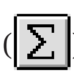


⑦ Put the 50 g mass on the Mass Hanger and wind up the thread. Click on the Record button (

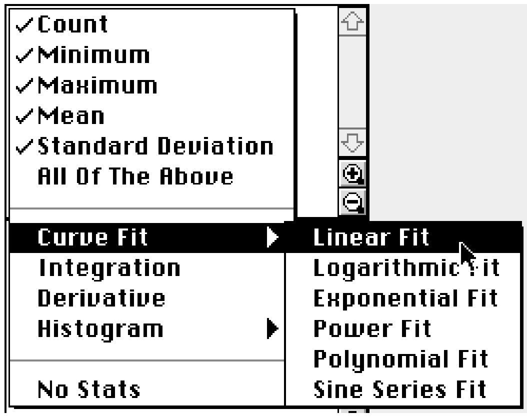
); then release the 3-step Pulley, allowing the mass to fall. Click the Stop button (

) to end the data collection.

➤ **HINT**: Click the stop button before the mass reaches the floor or the end of the thread to avoid erroneous data.

⑧ In the Graph Display window, click on the Statistics button (

); then select the linear curve fit from the pop-up menu.



The slope of the linear fit represents the angular acceleration (α) and should be entered in Table 2.2.

Measure the Radius

① Using calipers, measure the diameter of the pulley about which the thread is wrapped and calculate the radius. Record in Table 2.2.

Finding the Acceleration of the Disk Alone

Since in **Finding the Acceleration of Ring and Disk** both the disk and the ring are rotating, 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.

① To do this, take the ring off the rotational apparatus and repeat **Finding the Acceleration of Ring and Disk** for the disk alone.

Calculations

Record the results of the following calculations in Table 2.3.

① Calculate the experimental value of the rotational inertia of the ring and disk together.

② Calculate the experimental value of the rotational inertia of the disk alone.

③ Subtract the rotational inertia of the disk from the total rotational inertia of the ring and disk. This will be the rotational inertia of the ring alone.

④ Use a percent difference to compare the experimental values to the theoretical values.

Table 2.1: Theoretical Rotational Inertia

Mass of Ring	
Mass of Disk	
Inner Radius of Ring	
Outer Radius of Ring	
Radius of Disk	

Table 2.2: Experimental Rotational Inertia Data

	Ring and Disk Combined	Disk Alone
Hanging Mass		
Slope		
Radius of Pulley		

Table 2.3: Results

Rotational Inertia of Ring and Disk	
Rotational Inertia of Disk Alone	
Rotational Inertia of Ring Alone	
% Difference for Disk	
% Difference for Ring	

Experiment 3: Conservation of Angular Momentum

EQUIPMENT REQUIRED

- *Science Workshop™ 700 Interface*
- Mini-Rotational Accessory (CI-6691)
- Base and Support Rod (ME-9355)
- paper clips (for masses < 1 g)
- Rotary Motion Sensor (CI-6538)
- Mass and Hanger Set (ME-9348)
- Triple Beam Balance (SE-8723)
- calipers

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 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. The initial rotational inertia is that of a disk

$$I_i = \left(\frac{1}{2}\right)M_1R^2$$

and the final rotational inertia of the combined disk and ring is

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

where r_1 and r_2 are the inner and outer radii of the ring.

So the final rotational speed is given by

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

Setup

① Mount the RMS to a support rod and connect it to a computer. Place the disk directly on the pulley as shown in Figure 3.1.

② Run *Science Workshop*.

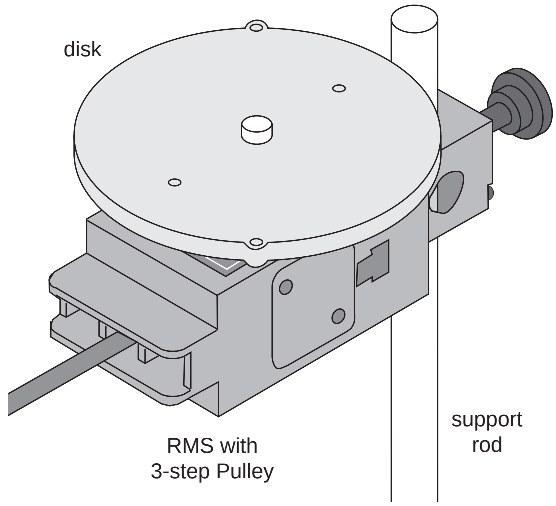
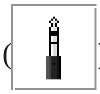
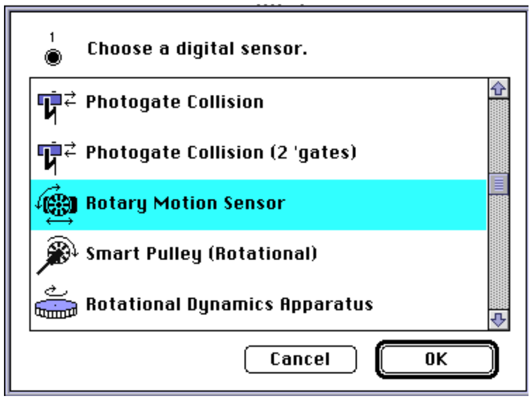


Figure 3.1: Setup for Dropping Ring Onto Disk

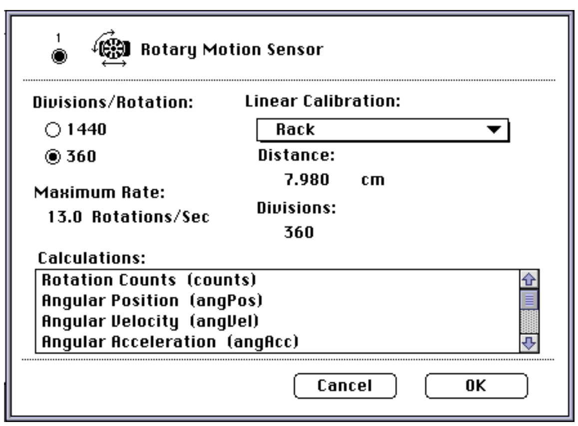
③ In the Experiment Setup window, click and drag a digital sensor icon () to the first of the two consecutive digital ports that the RMS is plugged into.

④ Select the RMS from the digital sensor menu and click OK.

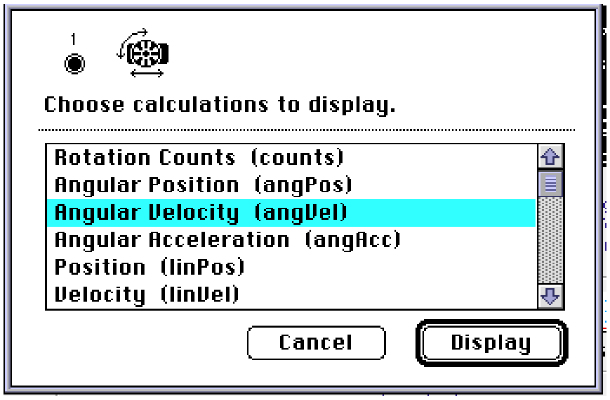


⑤ Double click the RMS icon in Experiment Setup window to activate the sensor dialog box for the RMS.

⑥ Ensure that the Divisions/Rotation radio button is in the 360 position.



⑦ Click and drag a Graph to the RMS icon and select “Angular Velocity” from the built-in calculations window; click OK.



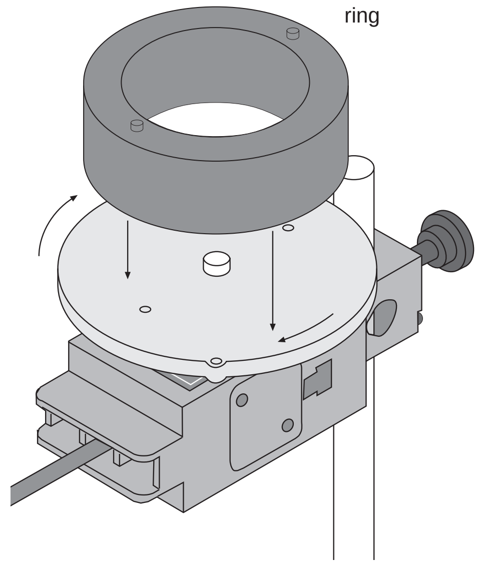
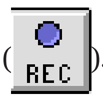
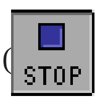
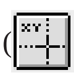


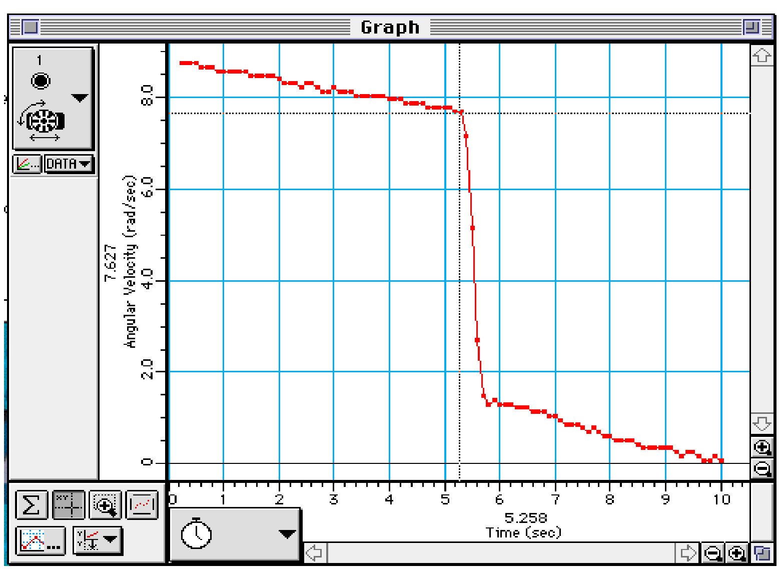
Figure 3.2: Drop Ring on Disk

Procedure

① Hold the ring with the pins up just above the center of the disk. Give the disk a spin using your hand and click the Record button (). After about 25 data points have been taken, drop the ring onto the spinning disk. See Figure 3.2.

② Click on the Stop button () to end the data collection.

③ Click on the Smart Cursor button () and move the cursor to the data point immediately before the collision. Record the Angular Velocity at this point in Table 3.1. Move the cursor to the data point immediately after the collision. Record the Angular Velocity at this point in Table 3.1.



④ Weigh the disk and ring and measure the radii. Record these values in Table 3.1.

Analysis

① Calculate the expected (theoretical) value for the final angular velocity and record this value in Table 3.1.

② Calculate the percent difference between the experimental and the theoretical values of the final angular velocity and record in Table 3.1.

Questions

① Does the experimental result for the angular velocity agree with the theory?

② What percentage of the rotational kinetic energy was lost during the collision? Calculate the energy lost and record the results in Table 3.1.

$$\%KE\ Lost = \frac{\frac{1}{2}I_i\omega_i^2 - \frac{1}{2}I_f\omega_f^2}{\frac{1}{2}I_i\omega_i^2}$$

Table 3.1: Data and Results

Initial Angular Velocity	
Final Angular Velocity (experimental value)	
Mass of Disk (M_1)	
Mass of Ring (M_2)	
Inner Radius of Ring (r_1)	
Outer Radius of Ring (r_2)	
Radius of Disk (R)	
Final Angular Velocity (theoretical value)	
% Difference Between Final Angular Velocities	
% KE lost	

Suggested Experiments

Experiment 4: Force versus Displacement – Collision between Cart and Force Sensor

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– IDS Mount Accessory (CI-6692)
– Dynamics Track (ME-9435A)
– Accessory Bracket with Bumpers (CI-6545)
– paper clips (for masses < 1 g)
– Rotary Motion Sensor (CI-6538)
– Force Sensor (CI-6537)
– Dynamics Cart (ME-9430)
– string

Purpose

The purpose of this experiment is to see the dependence of magnetic and spring forces on distance.

Procedure

① Mount the Force Sensor on one end of the Dynamics Track using the Accessory Bracket. Put the magnetic bumper on the Force Sensor.

② Attach the Rotary Motion Sensor to the other end of the track using the IDS Mount Accessory.

③ Put the cart on the track with its magnetic bumper facing the Force Sensor. Attach one end of a string to the cart and hang a mass (paper clip) on the other end of the string over the Rotary Motion Sensor pulley.

④ Set up *Science Workshop* to make a graph of force versus distance. The resolution of the Rotary Motion Sensor should be set on 1440 divisions per rotation.

⑤ With the cart's magnetic bumper facing the Force Sensor, push the cart against the Force Sensor and begin recording data. Then release the cart and let it move away from the Force Sensor. Is the force linear with distance?

⑥ Replace the magnetic bumper with a spring bumper and repeat the experiment.

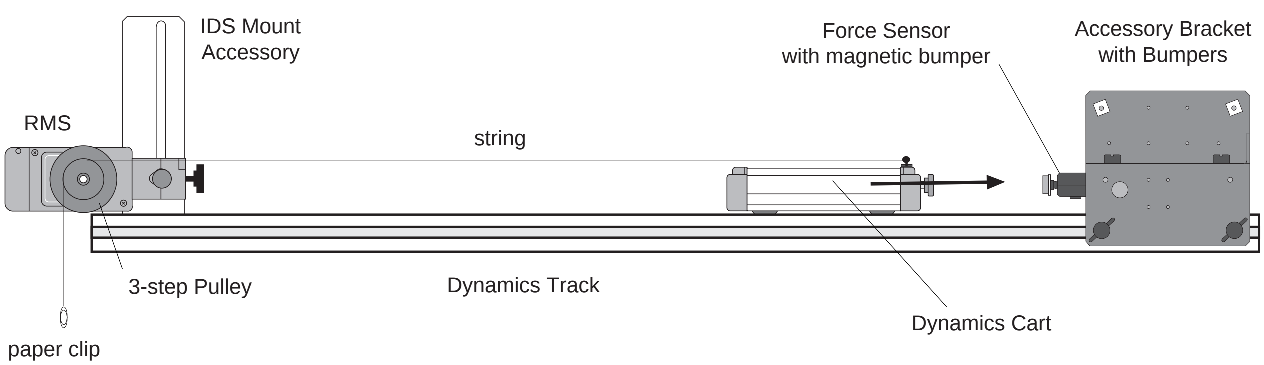


Figure 4.1: Experiment Setup

Experiment 5: Acceleration of Cart with Massive Pulley

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– IDS Mount Accessory (CI-6692)
– Dynamics Track (ME-9435A)
– Mass and Hanger Set (ME-9348)
– Rotary Motion Sensor (CI-6538)
– Mini-Rotational Accessory (CI-6691)
– Dynamics Cart (ME-9430)
– string

Purpose

The disk acts as a massive pulley, the rotational inertia of which cannot be ignored. A cart is accelerated by hanging a weight over the massive pulley and the resulting maximum speed depends on the mass of the cart and the rotational inertia of the pulley. Energy (including rotational kinetic energy) is conserved.

Procedure

① Attach the Rotary Motion Sensor to the Dynamics Track using the IDS Mount Accessory. Mount the disk on the 3-step Pulley on the Rotary Motion Sensor.

② Put the cart on the track and attach one end of a string to the cart and hang a mass on the other end of the string over the Rotary Motion Sensor pulley.

③ Set up *Science Workshop* to make a graph of velocity versus time. The resolution of the Rotary Motion Sensor should be set on 360 divisions per rotation.

④ Start the cart at rest at the end of the track furthest away from the pulley, with the hanging mass a known height above the floor. Begin recording before the cart is released and stop recording after the hanging mass hits the floor.

⑤ From the graph, find the maximum speed. Using Conservation of Energy, this maximum speed can be predicted from the distance the mass fell and the cart mass and rotational inertia of the disk pulley.

⑥ Remove the disk from the 3-step Pulley and repeat the experiment to see how the maximum speed is affected when the pulley is essentially "massless".

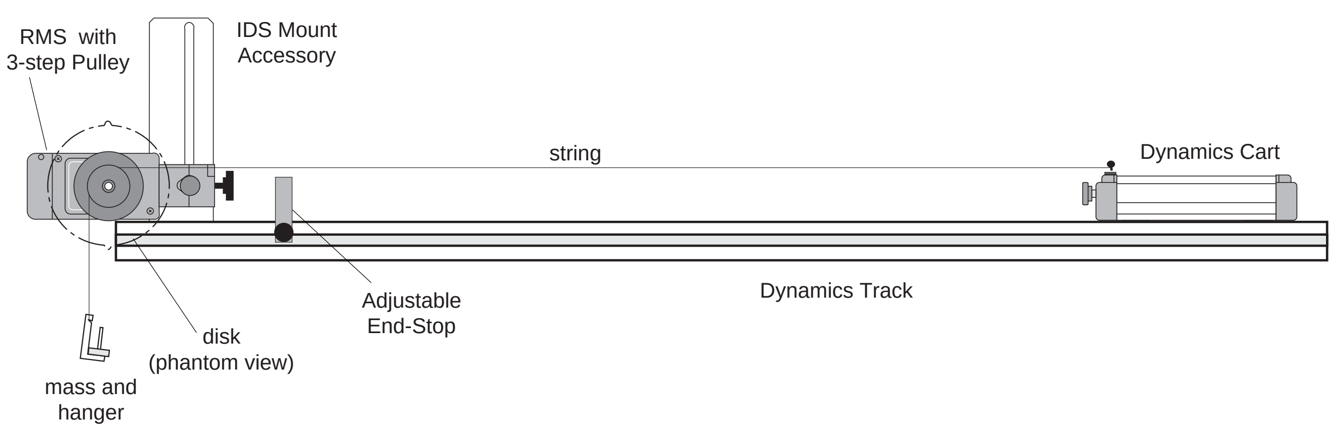


Figure 5.1: Experiment Setup

Experiment 6: Tension versus Angle

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– Force Sensor (CI-6537)
– (2) Pulley Mounting Rod (SA-9242)
– (2) Right Angle Clamp (SE-9444)
– rod for cross piece
– Rotary Motion Sensor (CI-6538)
– (2) Super Pulley (ME-9450)
– (2) Base and Support Rod (ME-9355)
– rod clamp
– string

Purpose

The tension in a string due to a hanging weight is examined as a function of the angle of the string.

Procedure

① Tie a string through the hole in the largest step of the 3-step Pulley on the RMS.

② Thread the string through a Super Pulley and over another Super Pulley and attach the end of the string to the force sensor. Attach a clamp to the hanging Super Pulley rod to add mass. The Super Pulley on the rod stand must be at the same height as the RMS 3-step Pulley.

③ Set up *Science Workshop* to make a graph of force versus angle. The resolution of the RMS should be set on 1440 divisions per rotation.

④ Before clicking on the record button, lift up on the hanging pulley and pull the string horizontal so the initial angle of the RMS will read zero when the string is horizontal. Begin recording in this position and put the hanging pulley back on the string.

⑤ Holding the Force Sensor in your hand, lower the hanging pulley slowly by moving the Force Sensor.

⑥ Use the calculator function in *Science Workshop* to calculate $1/\sin\theta$. Then plot force versus $1/\sin\theta$. The slope of the resulting straight line is related to the weight of the hanging pulley.

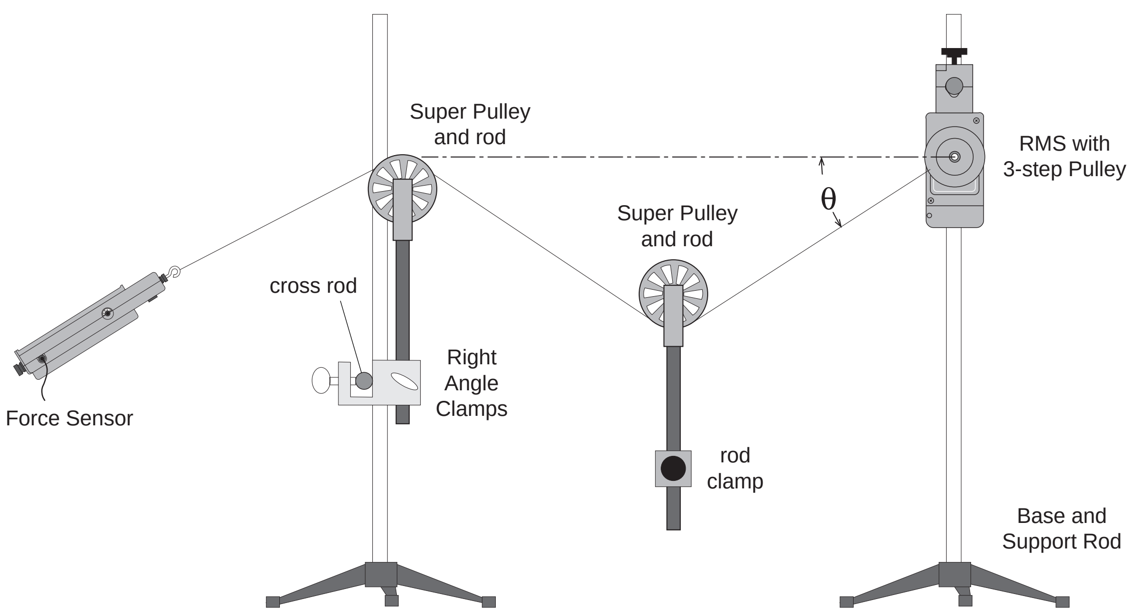


Figure 6.1: Experiment Setup

Experiment 7: Conservation of Angular Momentum – Colliding Disks

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– (2) Rotary Motion Sensor (CI-6538)
– (2) Mini-Rotational Accessory (CI-6691)
– (2) 3-step Pulley Accessory (CI-6693)
– (2) Base and Support Rod (ME-9355)

Purpose

Two rotating disks are pressed against each other to show that angular momentum is conserved.

Procedure

① Mount one RMS on a rod stand with the disk on top and mount the other RMS on the other rod stand with the disk on the bottom.

② Put a rubber o-ring on the large step of each of the 3-step Pulleys that do not have a disk attached to them. Adjust the height of each RMS so the rubber pulley on one matches the height of the other rubber pulley.

③ Set up *Science Workshop* to measure the angular speeds of both disks. The resolution of both Rotary Motion Sensors should be set on 360 divisions per rotation. Make two graphs: angular speed of each disk versus time.

④ Start both disks spinning (in the same direction or opposite directions).

⑤ Start recording and move one rod stand toward the other so rubber pulleys rub against each other.

⑥ Check to see if angular momentum is conserved in the collision.

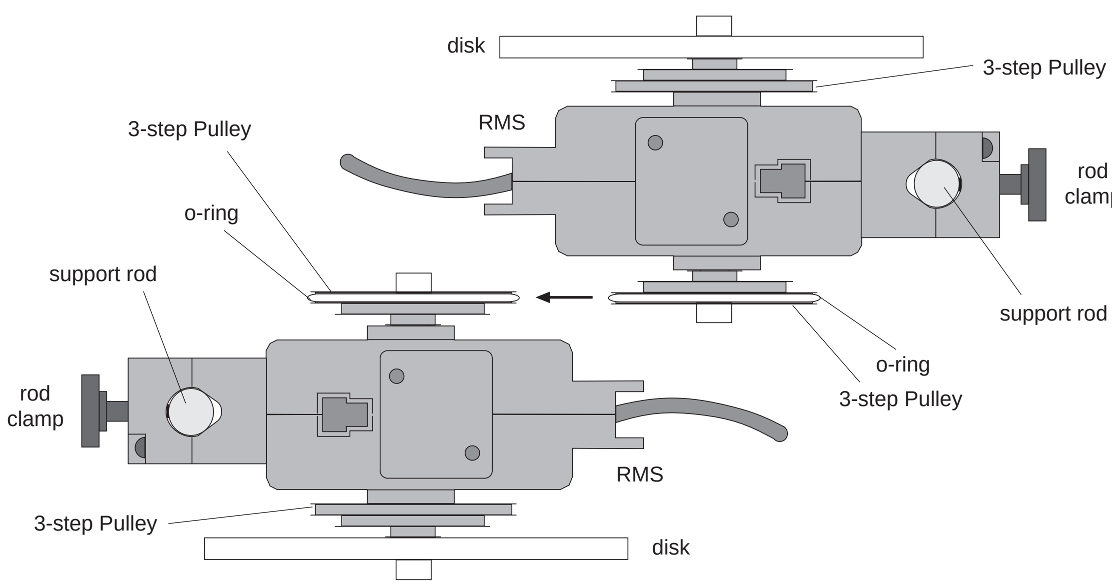


Figure 7.1: Experiment Setup

Experiment 8: Simple Harmonic Motion – Cart and Springs

EQUIPMENT NEEDED

- *Science Workshop™ 700 Interface*
- IDS Mount Accessory (CI-6692)
- Dynamics Track (ME-9435A)
- Accessory Bracket with Bumpers (CI-6545)
- (2) spring
- Rotary Motion Sensor (CI-6538)
- Force Sensor (CI-6537)
- Dynamics Cart (ME-9430)
- Adjustable End-Stop
- string

Purpose

The purpose is to examine the relationship between the spring force and the displacement, velocity, and acceleration of an oscillating cart.

Procedure

① Mount the force sensor and the RMS on the Dynamics Track. Tie a string to the Force Sensor hook, wrap it around the RMS pulley and attach the other end of the string to a spring.

② Attach the spring to a Dynamics Cart and attach a second spring to the other end of the cart. Fasten the end of the second spring to the Adjustable End-Stop on the track.

③ Set up *Science Workshop* to graph the force as a function of displacement, velocity, and acceleration. The resolution should be set to 360 divisions per rotation.

④ Start recording with the cart in its equilibrium position. Then pull the cart back and let it go.

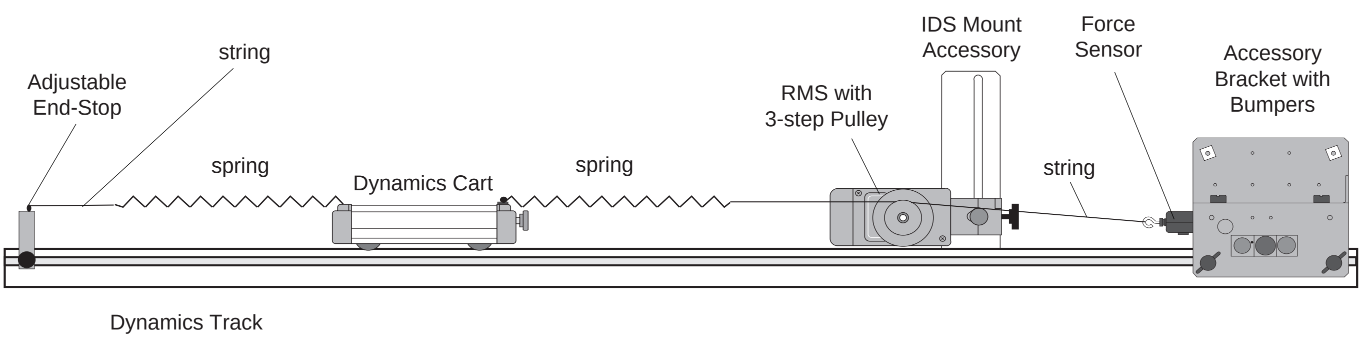


Figure 8.1: Experiment Setup

Experiment 9: Damped Pendulum

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– Rotary Motion Sensor (CI-6538)
– Chaos Accessory (CI-6689)
– Base and Support Rod (ME-9355)

Purpose

The purpose is to show the motion of a magnetically damped physical pendulum.

Procedure

① Mount the RMS on a rod stand and attach the disk with mass to the RMS.

② Mount the magnetic damping attachment on the side of the RMS.

③ Set up *Science Workshop* to plot angle versus time. The resolution should be set on 1440 divisions per rotation.

④ Begin recording with the mass at the bottom. Then pull the mass to the side and let the pendulum oscillate. Try different damping by adjusting the distance of the magnet from the disk. Determine the period and damping coefficient for different amounts of damping.

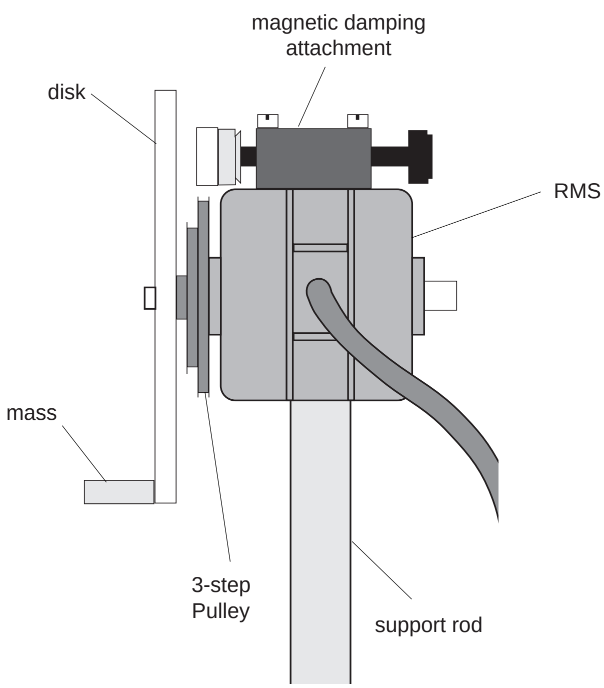


Figure 9.1: Experiment Setup

Experiment 10: Coupled Pendula

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– (2) Rotary Motion Sensor (CI-6538)
– (2) Mini-Rotational Accessory (CI-6691)
– (2) Base and Support Rod (ME-9355) connected by a cross rod
– rubber band for coupling

Purpose

The purpose is to show the energy exchange and the phase difference between two coupled pendula.

Procedure

① Attach two Rotary Motion Sensors to the rod as shown. Each RMS should have a rod mounted to the 3-step Pulley. Adjust the masses on the rods so they are exactly the same distance from the axis of rotation.

② Stretch a rubber band from the top of one RMS rod to the top of the other RMS rod.

③ Set up *Science Workshop* to plot angular speed of each pendulum versus time.

④ Pull back on one of the pendula and let it swing. Monitor the data and compare the velocities of each pendulum as time passes.

⑤ Move the mass up slightly on one pendulum to show that the coupling is not complete when the periods are different.

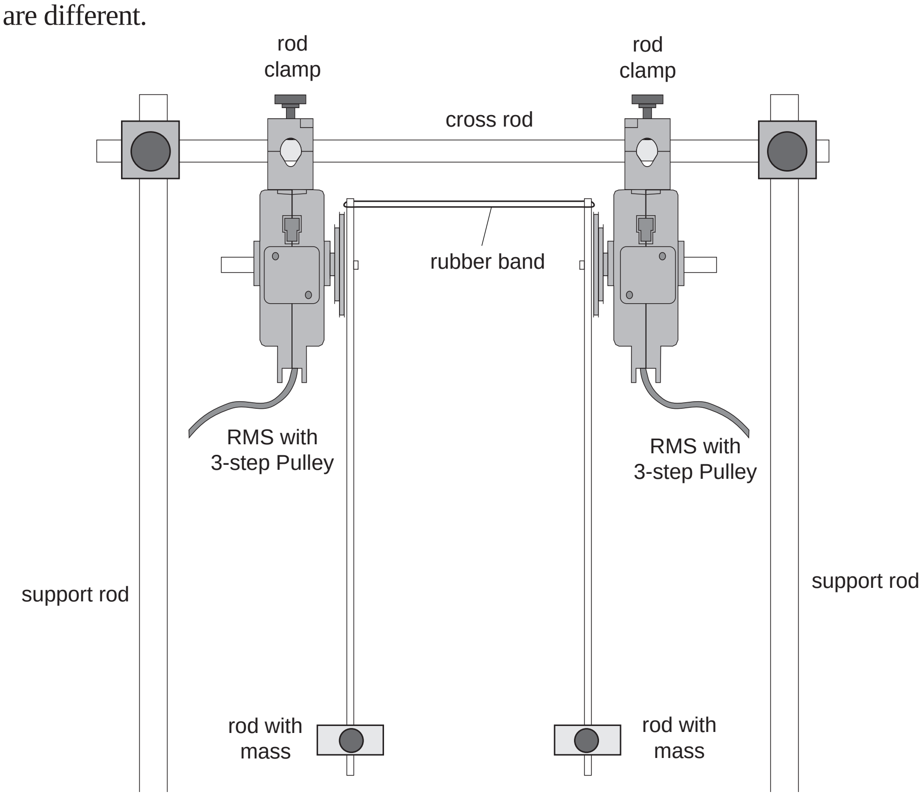


Figure 10.1: Experiment Setup

Experiment 11: Chaos

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– Chaos Accessory (CI-6689)
– 1.2 m Dynamics Track (ME-9435A)
– 0-12 V DC variable power supply
– Rotary Motion Sensor (CI-6538)
– IDS Mount Accessory (CI-6692)
– Mechanical Oscillator/Driver (ME-8750)

Purpose

The purpose is to examine the different modes of oscillation of a damped driven physical pendulum caused by varying the driving amplitude, driving frequency, and magnetic damping.

Procedure

① Set up the equipment as shown below. The string makes one wrap around the largest step on the 3-step Pulley.

② Set up *Science Workshop* to graph angular speed versus angular position. This is a phase plot. The resolution should be set on 1440 divisions per rotation.

③ The magnetic damping can be adjusted to vary the results but begin by varying the driving frequency of the Mechanical Oscillator/Driver. After each change in frequency, observe how the phase plot is affected.

④ Vary the driving amplitude and observe the changes in the phase plot.

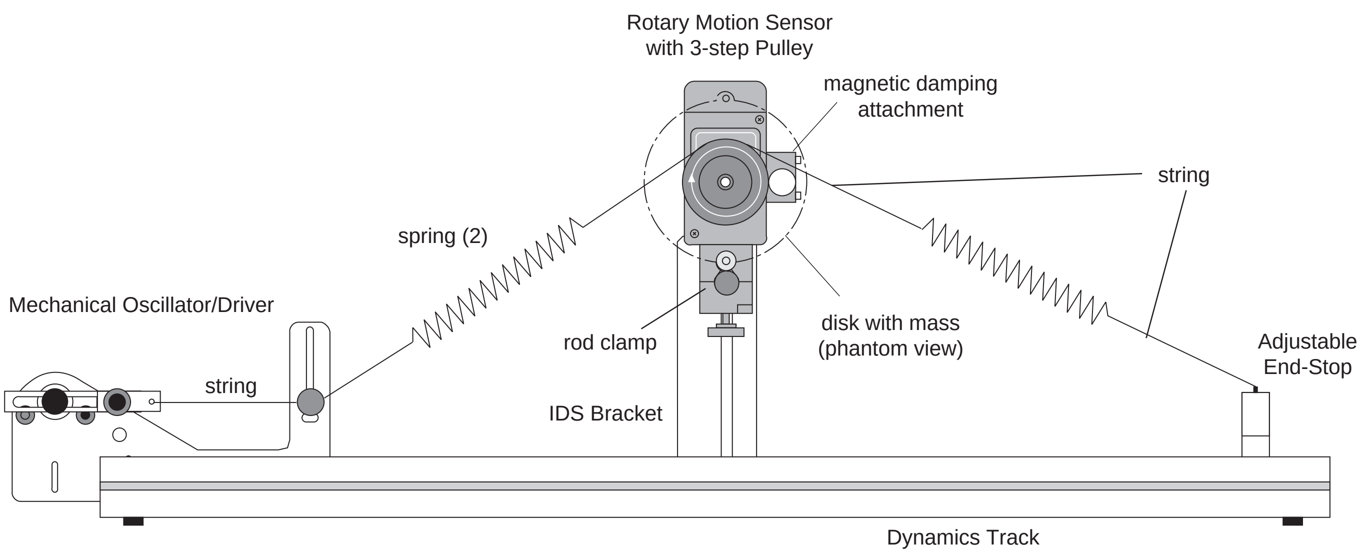


Figure 11.1: Chaos Experiment Setup

Experiment 12: Gyroscope Precession and Nutation

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– (2) Rotary Motion Sensor (CI-6538)
– “A”-Base Rotational Adapter (CI-6690)
– RMS/Gyroscope Mounting Bracket (ME-8963)
– Gyroscope (ME-8960)

Purpose

The purpose is to plot out the precession and nutation patterns for three different initial conditions.

Procedure

Please refer to the instruction manual supplied with the Gyroscope on how to set up and adjust the Gyroscope.

① Mount one RMS to the “A” base of the Gyroscope and mount the other RMS to the rotating shaft of the Gyroscope.

② Set up *Science Workshop* to graph nutation (tilt) angle versus precession angle. The resolution for both Rotary Motion Sensors should be set on 360 divisions per rotation.

③ Spin the gyroscope disk at various speeds, releasing the Gyroscope from rest at different angles. Also try releasing the Gyroscope with an initial velocity in the direction of the precession and with an initial velocity against the direction of precession.

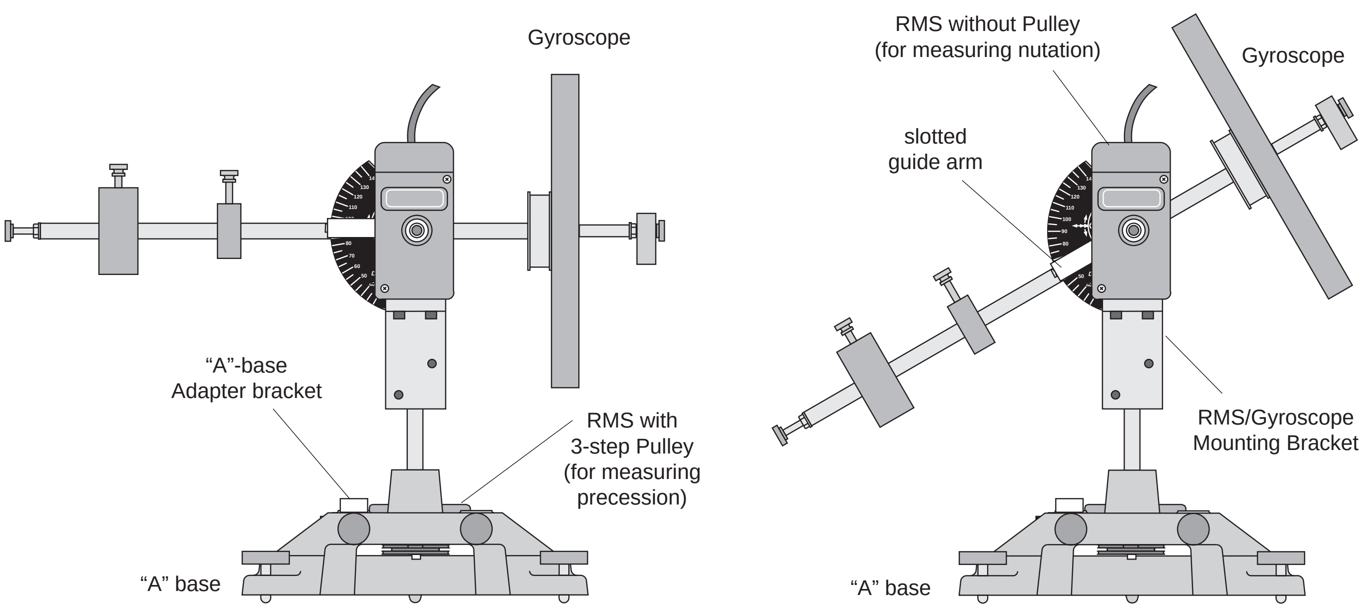


Figure 12.1: Experiment Setup for Precession and Nutation

Experiment 13: Buoyant Force versus Height Submerged

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Super Pulley (ME-9450)
– (2) Base and Support Rod (ME-9355)
– Force Sensor (CI-6537)
– Pulley Mounting Rod (SA-9242)
– Right Angle Clamp (SE-9444)
– string
– cylindrical object (with density greater than the fluid so it will sink)
– beaker with water or any other fluid (beaker must be big enough to completely submerge the cylindrical object)

Purpose

The relationship between buoyant force and depth in the fluid is determined. Also the density of the fluid can be determined.

Procedure

① Suspend the cylindrical object above the fluid as shown.

② Set up *Science Workshop* to plot force versus distance. The resolution should be set on 1440 divisions per rotation.

③ Hold the Force Sensor so the object is just above the fluid. Start recording and slowly lower the object into the water by moving the Force Sensor.

④ From the slope of the straight-line graph of force versus distance, determine the density of the fluid.

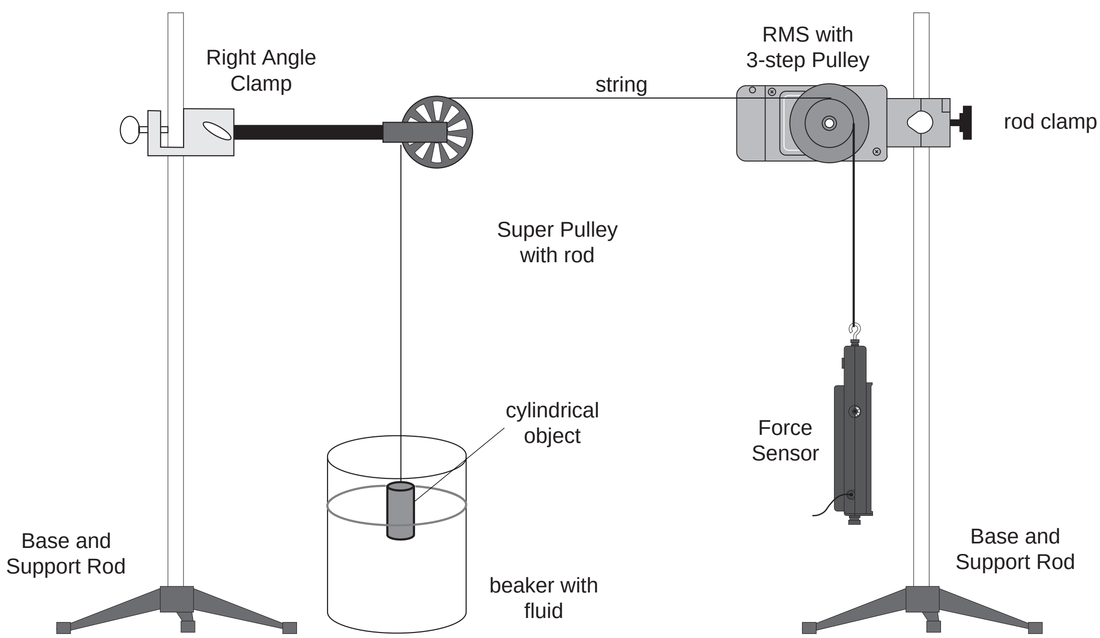


Figure 13.1: Experiment Setup

Experiment 14: Pressure versus Depth in a Fluid

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Linear Motion Accessory (CI-6688)
– Low Pressure Sensor (CI-6534)
– Base and Support Rod (ME-9355)
– small rubber balloon
– large beaker filled with water or other fluid

Purpose

The relationship between pressure and depth in a fluid is determined. Also the density of the fluid can be determined.

Procedure

① Mount the RMS above the water as shown.

② Insert the end of the pressure sensor tube into the small balloon. The balloon acts as a flexible diaphragm. Gently clamp the tube in the rod clamp at the end of the rack and insert the rack into the RMS.

③ Set up *Science Workshop* to plot pressure versus distance. The resolution should be set on 1440 divisions per rotation.

④ Hold the rack so the balloon is at the top of the water, just barely submerged. Start recording and slowly lower the balloon into the water by moving the rack.

⑤ From the slope of the straight-line graph of pressure versus distance, determine the density of the water.

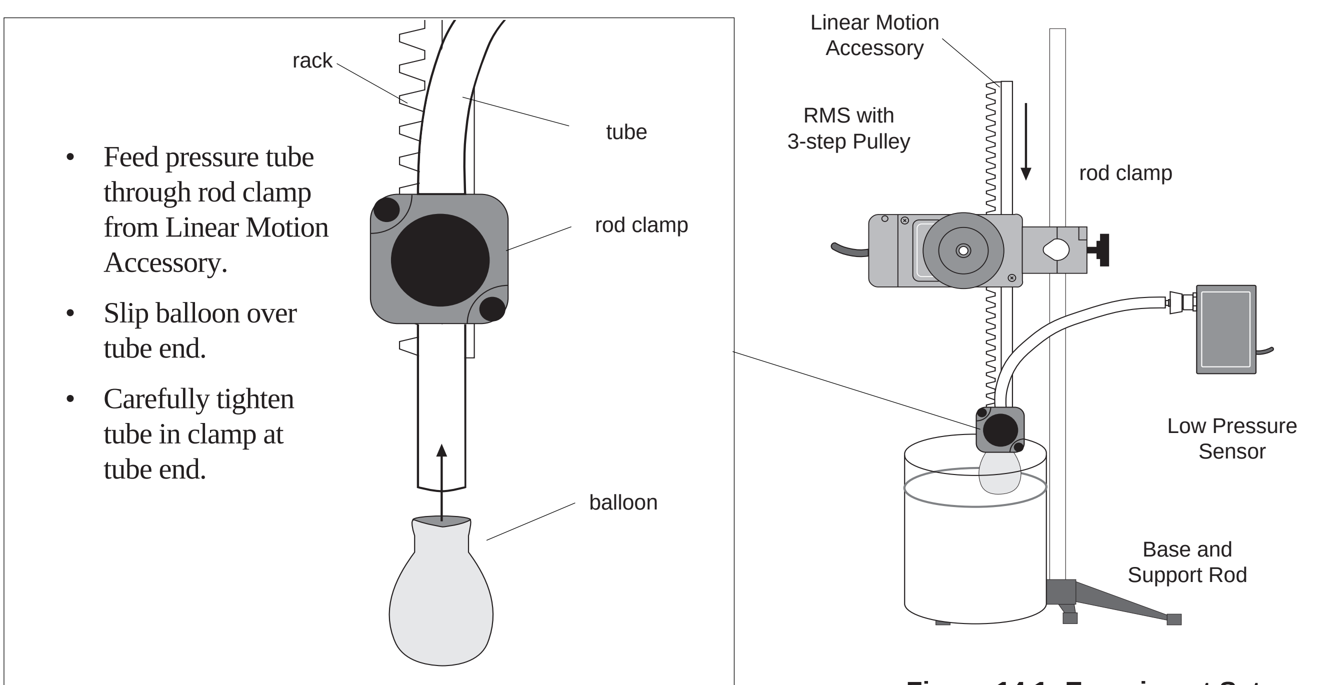


Figure 14.1: Experiment Setup

Experiment 15: Ideal Gas Law: Pressure versus Volume

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Linear Motion Accessory (CI-6688)
– Low Pressure Sensor (CI-6534)
– Force Sensor (CI-6537)
– Heat Engine/Gas Laws Apparatus (TD-8572)
– Base and Support Rod (ME-9355)

Purpose

A pressure versus volume diagram is obtained for a gas being compressed at constant temperature. The work done is calculated by integrating under the P-V curve. Also a plot of force versus piston displacement is obtained so the work can also be found by integrating under this curve.

Procedure

① Mount the RMS on a rod above the heat engine, with the rack in a vertical position, resting on the platform of the heat engine.

② Attach the Low Pressure Sensor to one of the Heat Engine outlets and clamp the other outlet closed.

③ Set up *Science Workshop* to plot pressure versus displacement. Alternatively, pressure versus volume can be plotted by using the calculator function in *Science Workshop* to multiply the displacement by the area of the piston. Also graph force versus position. The resolution should be set to 1440 divisions per rotation.

④ While recording, push slowly down on the piston by pushing down on the rack with the Force Sensor. This must be done slowly so the temperature does not change.

⑤ Integrate under the pressure versus volume curve and under the force versus distance curve to find the work done.

⑥ The initial volume of the cylinder can be determined using $P_oV_o = PV$, where $V_o = V + \Delta V$.

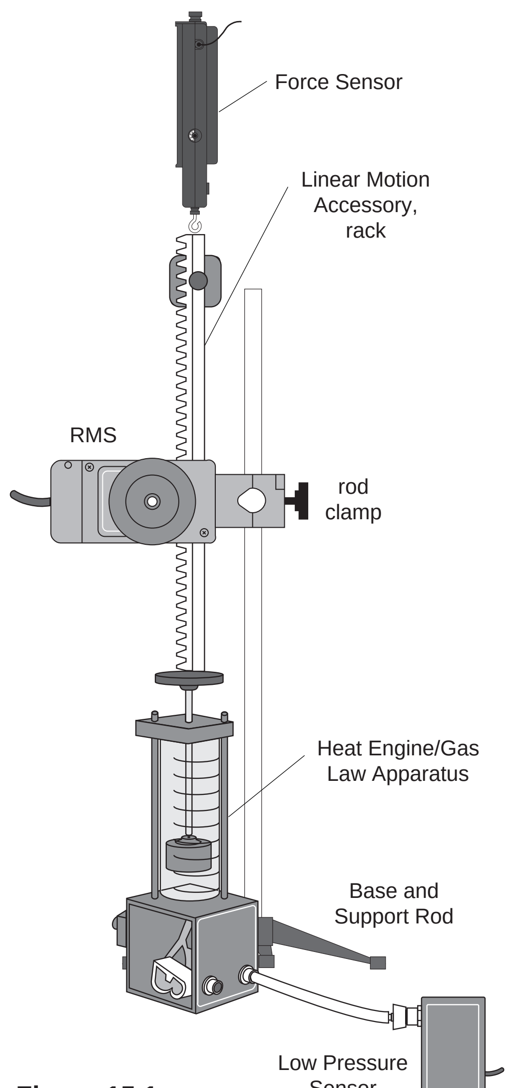


Figure 15.1: Experiment Setup

Experiment 16: Magnetic Field versus Distance

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Linear Motion Accessory (CI-6688)
– Magnetic Field Sensor (CI-6520)
– Base and Support Rod (ME-9355)
– neodymium magnet

Purpose

The magnetic field of a neodymium magnet is plotted as a function of distance from the magnet.

Procedure

① Mount the Rotary Motion Sensor with rack on a rod stand as shown.

② Gently clamp the rod portion of the Magnetic Field Sensor in the rod clamp on the rack.

③ Place a neodymium magnet on the table directly below the end of the Magnetic Field Sensor.

④ Set up *Science Workshop* to graph magnetic field versus distance. The resolution should be set to 1440 divisions per rotation.

⑥ Start recording with the Magnetic Field Sensor touching the magnet. Slowly pull up on the rack to move the magnetic sensor away from the magnet.

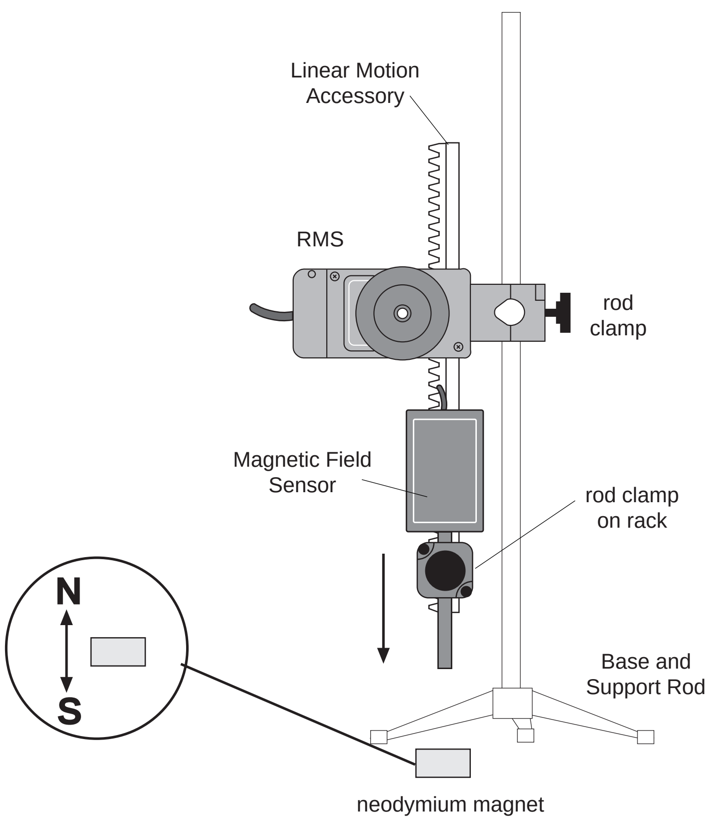


Figure 16.1: Experiment Setup

Experiment 17: Induced Voltage versus Position of Pendulum Coil and Magnet

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Voltage Sensor (CI-6503)
– 400-turn Detector Coil (EM-6711)
– Variable Gap Magnet (EM-8641)
– Base and Support Rod (ME-9355)

Purpose

The induced voltage in a coil is plotted as a function of angular position as it swings through a magnet.

Procedure

① Mount the Rotary Motion Sensor on a rod stand. Turn the 3-step Pulley so the rod guides face outward.

② Attach the Detector Coil wand to the shaft of the Rotary Motion Sensor and plug the Voltage Sensor into the Detector Coil.

③ Place the Variable Gap Magnet so the coil is able to swing through it.

④ Set up *Science Workshop* to plot voltage versus angular position. The resolution should be set to 1440 divisions per rotation.

⑤ Start recording with the wand hanging straight down. Pull the coil back and let it swing through the pendulum.

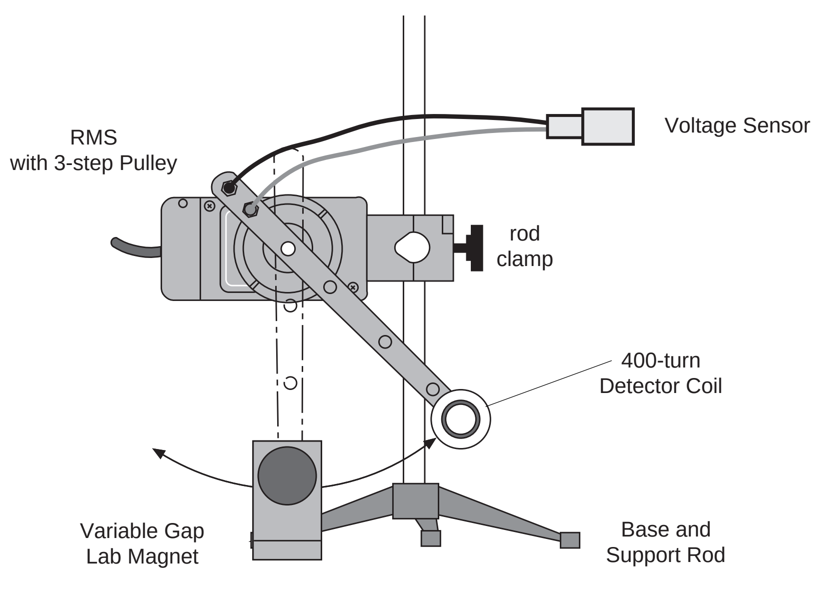


Figure 17.1: Experiment Setup

Experiment 18: Velocity of Aluminum Pendula Swinging through Magnet

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Variable Gap Magnet (EM-8641)
– Magnetic Force Accessory (EM-8642)
– Base and Support Rod (ME-9355)

Purpose

The angular speed of the paddle is plotted as a function of angular position as it swings through a magnet.

Procedure

① Mount the Rotary Motion Sensor on a rod. Turn the 3-step Pulley so the rod guides face outward.

② Mount the solid paddle on the Rotary Motion Sensor shaft.

③ Place the Variable Gap Magnet so the paddle is able to swing through it.

④ Set up *Science Workshop* to plot angular speed versus angular position. The resolution should be set to 1440 divisions per rotation.

⑤ Start recording with the paddle hanging straight down. Pull the paddle back and let it swing through the magnet.

⑥ Repeat with the other two types of paddles.

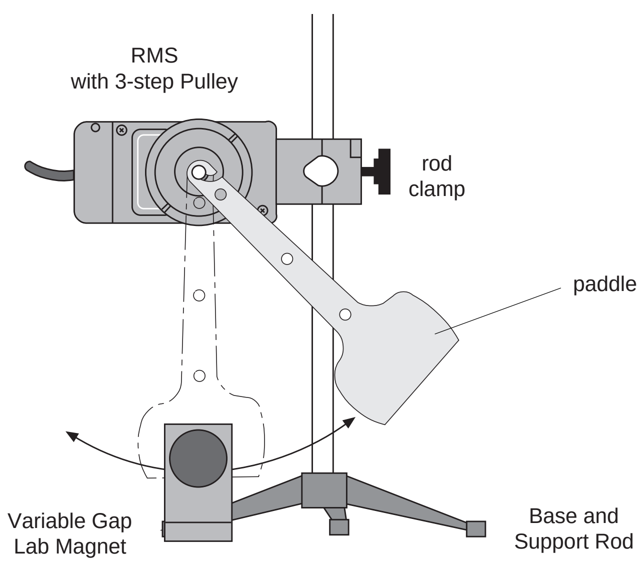


Figure 18.1: Experiment Setup

Experiment 19: Light Intensity versus Distance

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Dynamics Track (ME-9435A)
– Light Source (OS-8517)
– Mass and Hanger Set (ME-9348)
–block
– IDS Mount Accessory (CI-6692)
– Dynamics Cart (ME-9430)
– Light Sensor (CI-6504)
– string

Purpose

Light intensity is plotted as a function of distance from a point light source.

Procedure

① Attach the Rotary Motion Sensor to one end of the Dynamics Track using the IDS Mount Accessory. Mount the 3-step Pulley on the Rotary Motion Sensor.

② Put the cart on the track and place the Light Sensor, facing away from the RMS, on the cart.

③ Place the Light Source in point source mode at the opposite end of the optics bench. Adjust the Light Source or the Light Sensor so the Light Sensor and the point light source are at the same height.

④ Attach a string to the cart. Then pass the string over the Rotary Motion Sensor pulley and hang a mass (<10 gram) on the end of the string.

⑤ Set up *Science Workshop* to plot light intensity versus distance. The resolution should be set on 360 divisions per rotation.

⑥ Begin recording with the Light Sensor a known distance away from the point light source. As the Light Sensor moves away from the light, the string will rotate the Rotary Motion Sensor pulley.

⑦ The calculator function of *Science Workshop* can be used to add the known initial distance to the recorded distances.

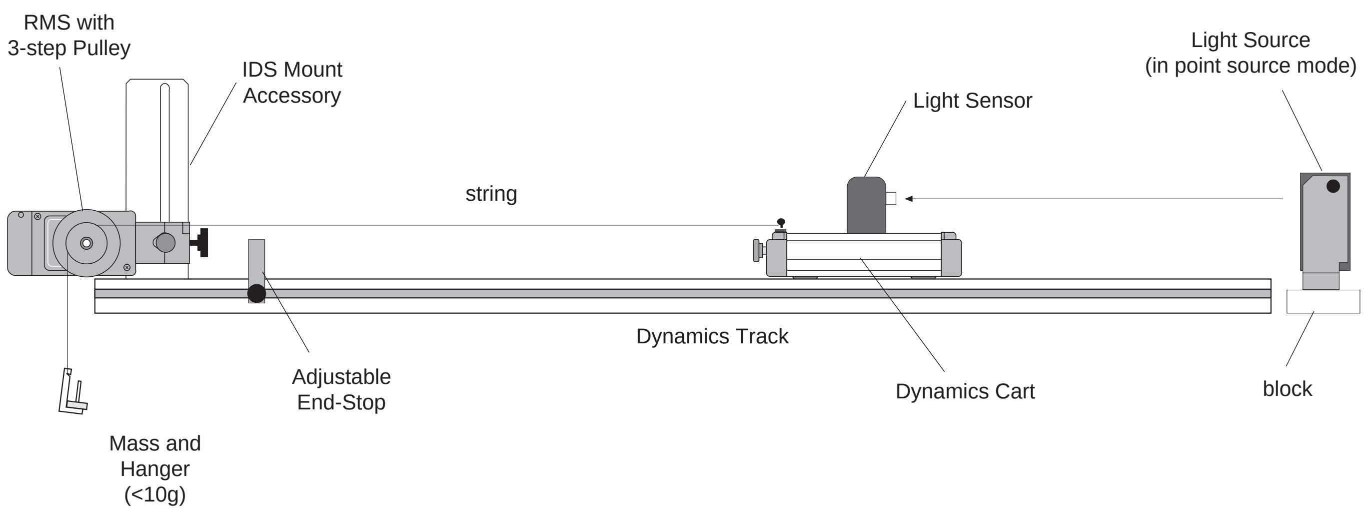


Figure 19.1: Experiment Setup

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

Web: http://www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

Title and Revision Date of software.

Type of Computer (Make, Model, Speed).

Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

Title and Model number (usually listed on the label).

Approximate age of apparatus.

A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

Part number and Revision (listed by month and year on the front cover).

Have the manual at hand to discuss your questions.