

Centripetal Force

Equipment:

INCLUDED:

1	Centripetal Force Apparatus	ME-8088
1	Force Sensor	PS-2104
1	Photogate Head	ME-9498A
1	Large Rod Base	ME-8735
1	90 cm Steel Rod	ME-8738
1	Multi-Clamp	SE-9507
1	45 cm Steel Rod	ME-8736
1	Banana Plug Cord-Red (5 pack)	SE-9750

NOT INCLUDED, BUT REQUIRED:

1	850 Universal Interface	UI-5000
1	PASCO Capstone	UI-5400

Introduction:

In this activity, students will use a Force Sensor and Photogate to discover the relationship of centripetal force, mass, (tangential) speed and radius for an object in uniform circular motion. Students will determine what happens to centripetal force as the result of changes in mass, speed, and radius.

Theory:

According to Newton's First Law, an object in motion tends to stay in motion in a straight line at a constant speed if there is no external net force applied to the object. An object undergoing uniform circular motion (motion in a circle at constant speed) must be acted on by a non-zero net force. That net force is called the centripetal force. It must point toward the center of the circle and have a constant magnitude given by:

$$F_c = mv^2/r \quad \text{Eq. (1)}$$

Where m is the mass of the object moving in a circle, r is the radius of the circle, and v is the (tangential) speed of the object. For uniform circular motion, the tangential speed is given by:

$$v = 2\pi r/T \quad \text{Eq. (2)}$$

where T is the time for one revolution.

It is important to note that the centripetal force is not an additional force on the system, but rather the vector sum of the forces acting on the object.

$$\mathbf{F}_c = \Sigma \mathbf{F} \quad \text{Eq. (3)}$$

Examples of centripetal force include the tension in a string attached to a can twirled in a circular path, the friction between the road and the tires of a car on an unbanked curve, or the force of gravity pulling a satellite toward the center of Earth as the satellite moves in a circular orbit.

Setup:



Figure 2: Complete Setup

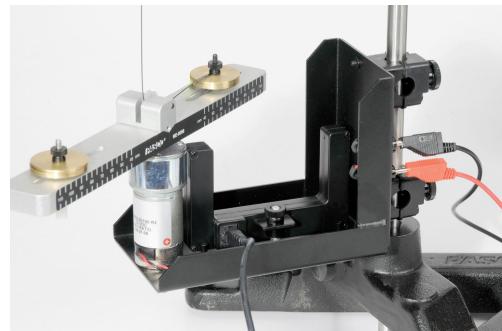


Figure 1: Photogate Attachment

1. Attach the Photogate to the frame of the Centripetal Force Apparatus as shown in Figure 1.
2. Attach the entire Centripetal Force Apparatus as low as possible to the 90cm rod and base.
3. Attach the 45cm rod horizontally to the 90 cm rod with the multi-clamp.
4. Hang the Force Sensor from the horizontal rod.
5. Screw the Ball Bearing Swivel to the Force Sensor.
6. Use a metal clip to attach the low-stretch cable to the Swivel. Thread the other end of the cable through the plastic pulley and attach it to the sliding post by putting the loop over the post and attaching the mass above it. Note: between uses, it is important to store the cable in a manner that does not put kinks in it.
7. Plug the Photogate into Digital Channel 1 on the 850 Universal Interface. Plug the Force Sensor into any *Pasport* input.
8. Click open the Signal Generator at the left of the screen. On 850 Output 1, the Waveform should be DC with a DC Voltage of 4.0 V. Click the Off button to be sure the Signal Generator is off and connect the Centripetal Force Apparatus to OUTPUT 1 on the 850 Universal Interface with banana plugs. It is not important which plug on the Centripetal Force Apparatus attaches to the red output although it will affect the rotation direction. Careful: if the Signal Generator is not off, the arm will begin to rotate! Click the Signal Generator again to close it.
9. Level the base. This must be done carefully for good results. Remove the counterweight mass and put a level on the rotating arm as shown in Figure 3. Start with the arm parallel to the two leveling screws in the base as shown in Figure 3. There is some play in the rotating arm. Tip it up or down a bit by pushing on the end of the rotating arm away from the level. Adjust the leveling screws until the bubble moves about the same amount on either side of center when you rock the arm up and down as in Figures 4a & 4b. Now rotate the arm 90° and repeat changing both screws by the same amount. Then rotate back to the original position and re-level if necessary.
10. Attach a 5 g counterweight mass.

11. Remove the assembly that holds the moving mass (black plastic nut and bolt, silver nut and two plastic washers) and determine its mass. Click open the Calculator at the left of the screen and repace the 0.0038 value in line 7 your measured mass (in kg) for "m hold".
12. Re-attach the assembly to the rotating arm with one plastic washer below the arm and one above. Then the silver nut, tightened down enough to prevent tipping, but the assembly must slide freely. Then the cable loop (see Figure 5). Then use the black nut to attach 5 g of mass above the loop. The cable loop should be below the 5 g mass. It is shown incorrectly in Figures 1&2.



Figure 3: Level Placement



Figure 4a & 4b: Rocking the Bubble



Figure 5: Slide Assembly

Setup C:

1. Now, adjust the height of the force sensor so that the 5g mass is about 10.0 cm from the center when there is just enough tension in the cable to straighten the cable. It is important that the force sensor be exactly above the center of the apparatus. To check this, pull on the mass to put tension in the cable. Then observe the cable from the front of the system to verify it is parallel to the 90 cm rod and measure the distance from the rod to the top of the string and to just above the pulley. Adjust the 45 cm rod holding the force sensor until the cable is parallel to the rod. Note that any time you change the position of the Force Sensor, you will have to repeat this step.
2. Pull the mass to tighten the cable to determine the actual radius to the nearest 0.1 cm. Although you can do this using the scale attached to the side of the apparatus, it is more precise to measure from the center of the mass to where the vertical cable is with a small ruler. Click open the Calculator at the left of the screen. In line 1, replace the 0.1 value (10cm) with the value that you actually measured. Click the Calculator again to close it.

Procedure m – Force vs Mass (Radius and Velocity held Constant)

1. Press the “ZERO” button on the Force Sensor. This should set the Force Sensor to zero since there should be no force on it at this point.
2. Click RECORD. Collect data for about 5 s and then click STOP to stop data collection. Mean speed and Mean Force should both be zero. If the Mean Force is not zero, record the value. It will help during the data analysis.
3. To avoid wobbling, tighten an identical mass (5 g here) to the opposite side of the rotating platform as a counterbalance so that it is as far from the center of the rotating platform as the distance you measured in step 2. This measurement need not be precise and it is sufficient to use the scale on the side of the apparatus.
4. Click on the Signal Generator at the left of the screen. Under the Output 1, set waveform to DC and the DC Voltage to 4.5 V. **Caution! The next step will cause the apparatus to begin rotation. Be sure it can do so without hitting anything or anybody.** Click the On button. After about 10 s, reduce the voltage to 4.0 V. Starting with a higher speed and then reducing it minimizes the frictional effects by positioning the mass at about the correct position before reducing the speed. Let it run for about 20 s to reach constant speed.
5. Press the RECORD button. Allow data collection to occur for approximately 10 seconds until the mean Values for Speed and Force are almost constant. Press the STOP button.
6. Click the Signal Generator Output 1 to Off. The rotation should stop.
7. In row 1 (5g row) of the Variable Mass table, enter the value of the Mean Speed into column 2 and record the Mean Force (ignore the minus sign) in column 3.
8. Increase the mass by 5.0 g (0.005kg).
9. Repeat steps 3-8 until you reach 30.0g of mass. Note that the mean speed should be about the same for all the runs.

Analysis m: Force vs Mass

1. Observe the Force vs Mass Graph. The “Av Force” is the measured average force from the table on the previous page.
2. Click open the Calculator at the left of the screen and examine lines 1-7 to verify that “theory force” is calculated using Equation 1 from Theory. Note that the actual measured speed, “Av speed” from the Variable Mass table on the previous page is used to calculate “theory force”. Since the speed is not quite constant, the “theory force” points are not quite linear. Click the Calculator to close it.
3. The mass sometimes hangs up a little causing an obviously bad “Av Force” point. You should repeat the run for any bad point and see if it improves. Enter the new run in the row below the 0.030 kg row of the Variable Mass table on the previous page.
4. Select the “Av Force” data by clicking in the Legend box or on a data point. Then click the black triangle by the Curve Fit tool in the graph toolbox and select Linear.

Procedure v: Force vs Speed (Radius and Mass held Constant)

1. Keep the **30g** mass attached to the cable and the rotating platform as it was in Procedure m.
2. Click on the Signal Generator at the left of the screen. Under the Output 1, set the DC Voltage to 5.5 V. **Caution! The next step will cause the apparatus to begin rotation. Be sure it can do so without hitting anything or anybody.** Click the On button. After about 10 s, reduce the voltage to 5.0 V. Let it run for about 20 s to reach constant speed.
3. Press the RECORD button. Allow data collection to occur for approximately 10 seconds until the mean Values for Speed and Force are almost constant. Press the STOP button.
4. In row 1 (5.0 V row) of the Variable Mass table, enter the value of the Mean Speed into column 2 and record the Mean Force (ignore the minus sign) in column 3.
5. Decrease the Signal Generator voltage by 0.5 V. Let it run for about 20 s to reach constant speed.
6. Repeat steps 3-5 until you reach 3.5 V.

Analysis v: Force vs Speed

1. Observe the Force vs Speed² Graph. The “Ave F” is the measured average force from the table on the previous page.
2. Click open the Calculator at the left of the screen and examine line 8 to verify that “theory f” is calculated using Equation 1 from Theory. Click the Calculator to close it.
3. The mass sometimes hangs up a little causing an obviously bad “Ave F” point. You should repeat the run for any bad point and see if it improves. Enter the new run in the row below the 3.5 V row of the Variable Speed table on the previous page.
4. Select the “Ave F” data by clicking in the Legend box or on a data point. Then click the black triangle by the Curve Fit tool in the graph toolbox and select Linear.

Procedure r: Force vs Radius (Mass and Time for one rotation held Constant)

1. Keep the **30g** mass attached to the cable and the rotating platform as it was in Procedure v.
2. Enter the radius of the circle in column 1 of the Variable Radius table. Note that the initial radius is the same as before and is recorded in line 1 of the Calculator. After you enter it, the value should also show in the Radius box in the upper left.
3. Click on the Signal Generator at the left of the screen. Under the Output 1, set the DC Voltage to 5.0 V. **Caution! The next step will cause the apparatus to begin rotation. Be sure it can do so without hitting anything or anybody.** Click the On button. After about 10 s, reduce the voltage to 4.5 V. Let it run for about 20 s to reach constant speed.
4. Press the RECORD button. Allow data collection to occur for approximately 10 seconds until the mean Values for Speed and Force are almost constant. Press the STOP button.
5. In row 1 of the Variable Radius table, enter the value of the Mean Speed into column 2 and record the Mean Force (ignore the minus sign) in column 3.
6. Turn the Signal Generator Off. The rotation should stop.
7. Following the steps in Setup C, decrease the radius to about 8.5 cm. Measure the value of the radius to within 0.1 cm. Move the counterweight mass to about the same distance. Repeat steps 2-6.
8. Continue as above for radii of about 7 cm and 5 cm.

Analysis r: Force vs Circle Radius

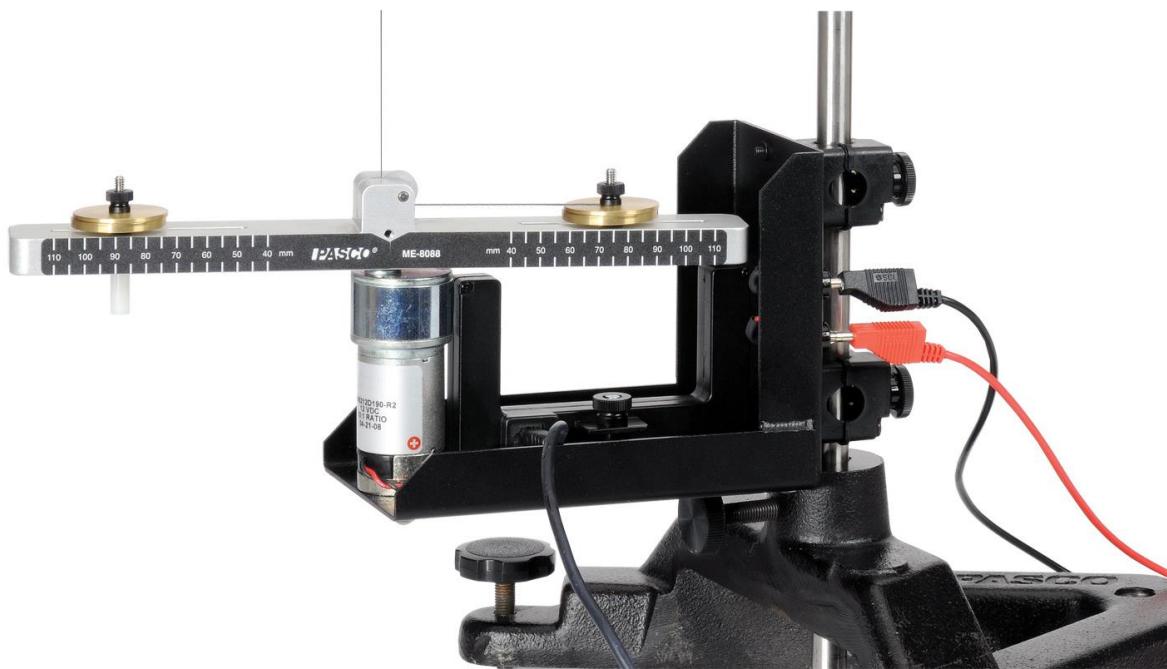
1. Observe the Force vs Radius, r , Graph. The “Ave Force” is the measured average force from the table on the previous page.
2. Click open the Calculator at the left of the screen and examine lines 9 & 10 to verify that “theo f” is calculated using Equation 1 from Theory. Note that the actual measured speed, “Ave speed” from the Variable Mass table on the previous page is used to calculate “theo f”. Since the speed is not quite constant, the “theo f” points are not quite linear. Click the Calculator to close it.
3. The mass sometimes hangs up a little causing an obviously bad “Ave Force” point. You should repeat the run for any bad point and see if it improves. Enter the new run in the Variable Mass table on the previous page.
4. Select the “Ave Force” data by clicking in the Legend box or on a data point. Then click the black triangle by the Curve Fit tool in the graph toolbox and select Linear.

Conclusions:

1. Looking at the graph on the “Analysis m” tab, what can you conclude about the relationship between the centripetal force and mass? Explain how you know.
2. Looking at the graph on the “Analysis v” tab, what can you conclude about the relationship between the centripetal force and tangential speed? Explain how you know.
3. Looking at the graph on the “Analysis r” tab, what can you conclude about the relationship between the centripetal force and radius of the circle? Explain how you know.
4. Considering the answers to the first three questions, is Equation 1 from Theory valid. Careful...how can the relationship you saw in Question 3 agree with Equation 1?
5. How would friction between the mass and the rotating arm affect your values for the measured force?



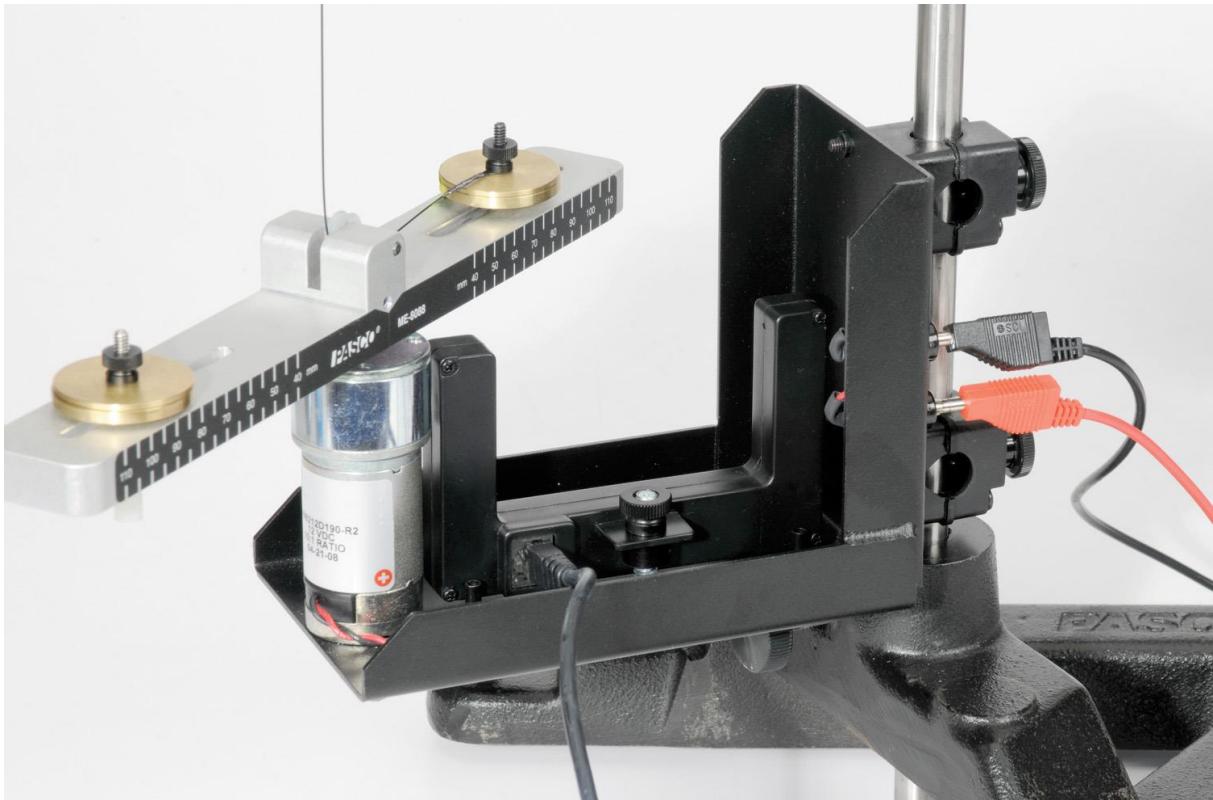




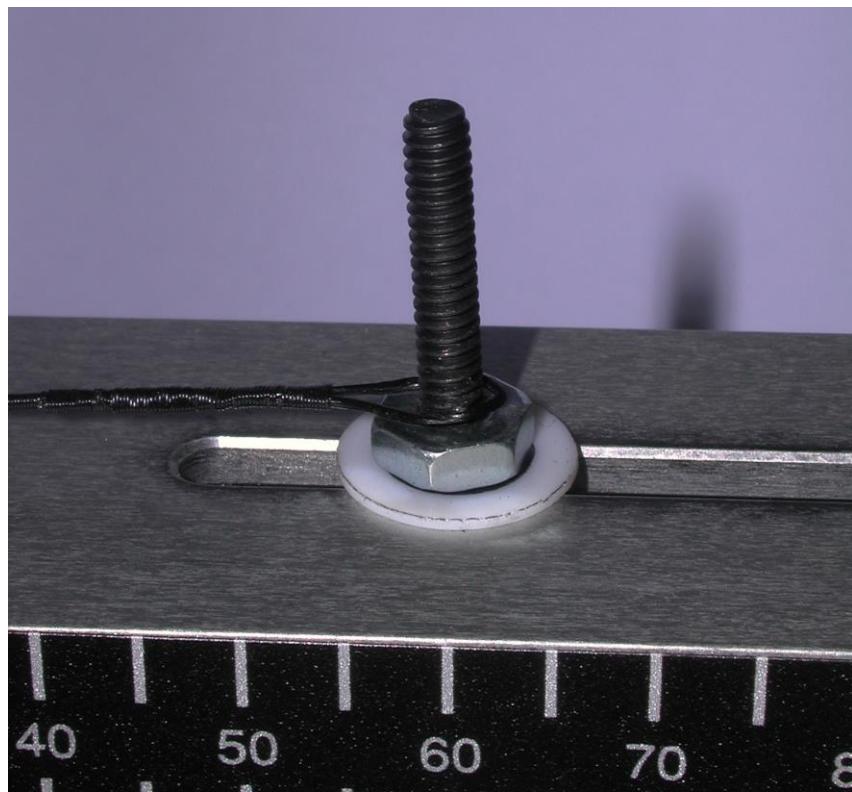
Level on Arm

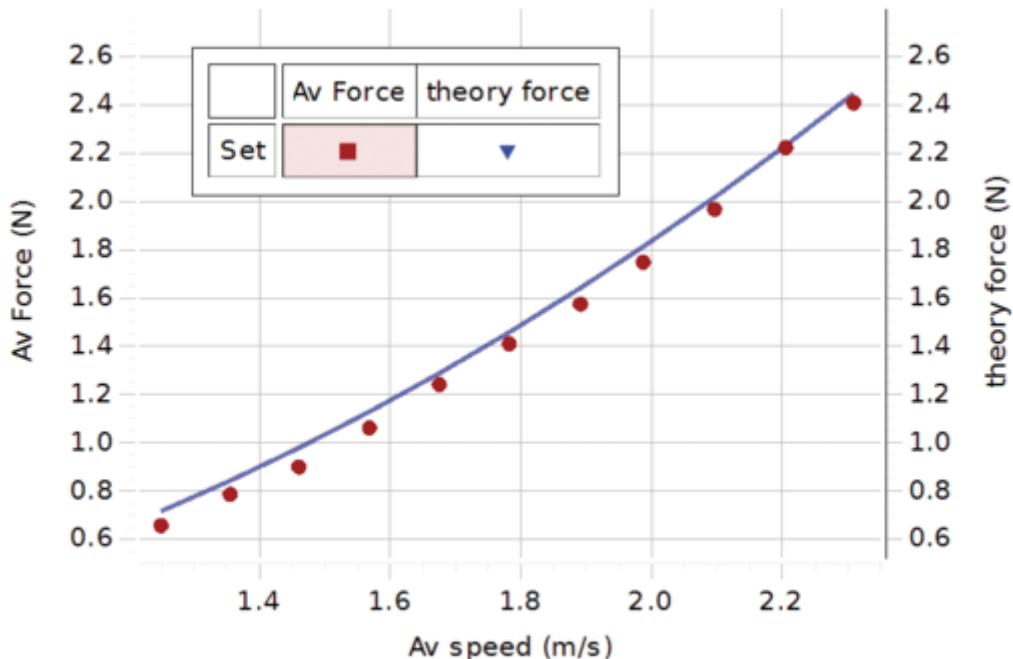


Photogate placement



Sliding





Centripetal Force on a 34 g mass moving in a 7.0 cm circle

5x Banana Plug Cord-Red (5 Pack) (SE-9750)

Product Summary

These heavy, insulated patch cords are convenient, durable and inexpensive. The grips are stackable and made of soft plastic for flexible strain relief. The spring connectors rotate in the grips, reducing wear due to friction.



1x 45 cm Stainless Steel Rod (ME-8736)

Product Summary

These 45 cm long, non-threaded stainless steel rods are ideal for providing support to your experiments in the lab. They are non-magnetic, very rigid, and durable. Unlike aluminum rods, they do not mar. The rods have a diameter of 12.7 mm (1/2 inch).



1x 90 cm Stainless Steel Rod (ME-8738)

Product Summary

These 90 cm long, non-threaded stainless steel rods are ideal for providing support to your experiments in the lab. They are non-magnetic, rigid, and durable. Unlike aluminum rods, they do not mar. Rods have a diameter of 12.7 mm (1/2 inch).



Photogate Head (ME-9498A)

Product Summary

The Photogate Head monitors the motion of objects passing through its gate, counting events as the object breaks the infrared beam.

Includes a swivel mount to attach to a photogate stand. It does not include the heavy base and standard rod of the Accessory Photogate (ME-9204B). Can be used with ScienceWorkshop interfaces or with PASPORT interfaces using Digital Adapter (PS-2159).

Applications

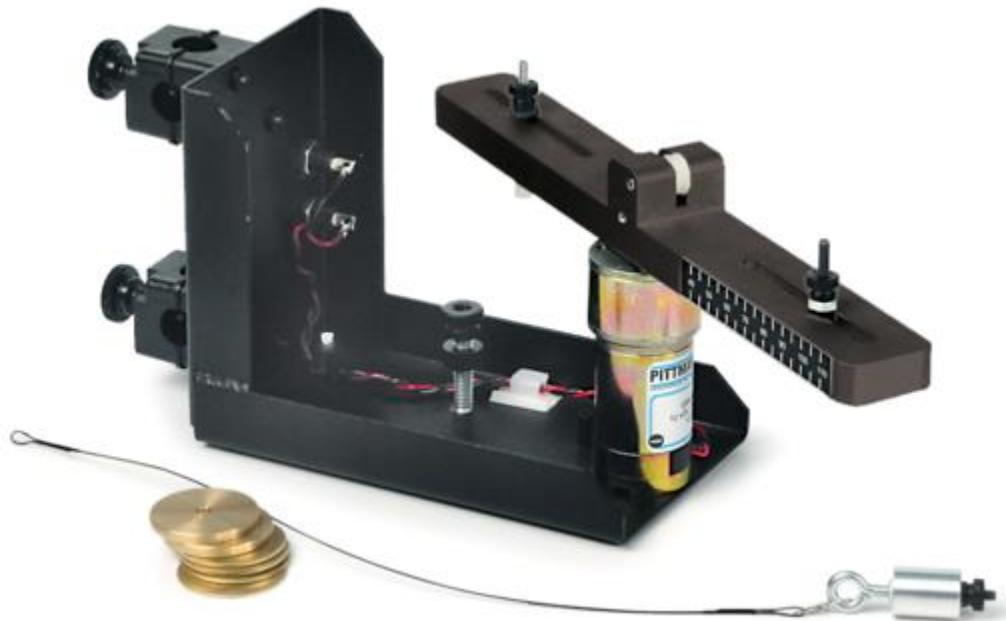
- Conduct basic motion experiments
- Measure acceleration of freefall
- Measure pendulum periods

What's Included

- 1x Photogate Head with cable



1x Centripetal Force Apparatus (ME-8088)



Product Summary

The study of circular motion traditionally involves examining relationships between centripetal force, velocity, radius and mass. However, these relationships are difficult to observe using traditional physics apparatus. One common experiment involves the swinging of rubber stoppers over a student's head. The Centripetal Force Apparatus combines the "swinging mass" approach with sensors and a high-quality electric motor to create a system that allows students to discover these relationships empirically.

Features

- Stable Frame: The metal frame can be easily attached to a ring stand using the included clamp. The frame may also be attached to a tabletop with a large table clamp.
- High Quality Motor: Will withstand years of student use.
- Computer-based Measurements: The Force Sensor and photogate facilitate accurate and repeatable measurements of force, angular velocity and tangential velocity.

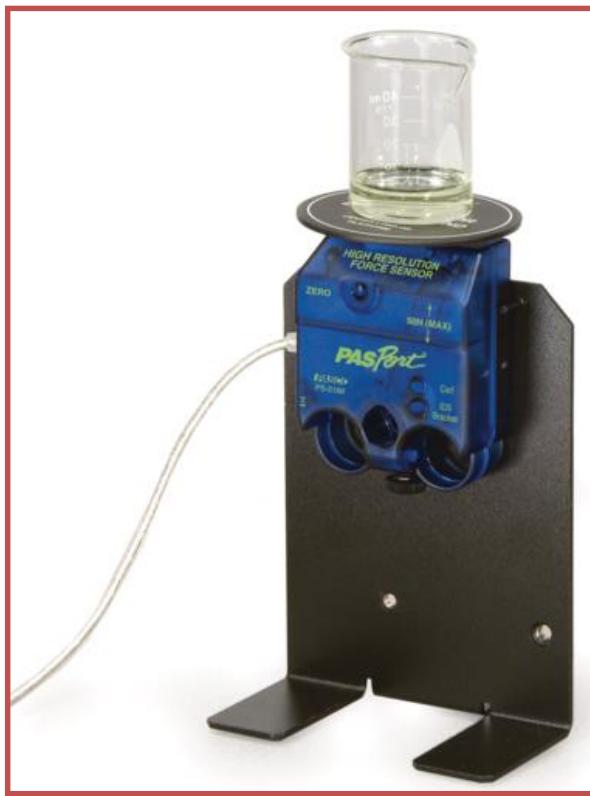
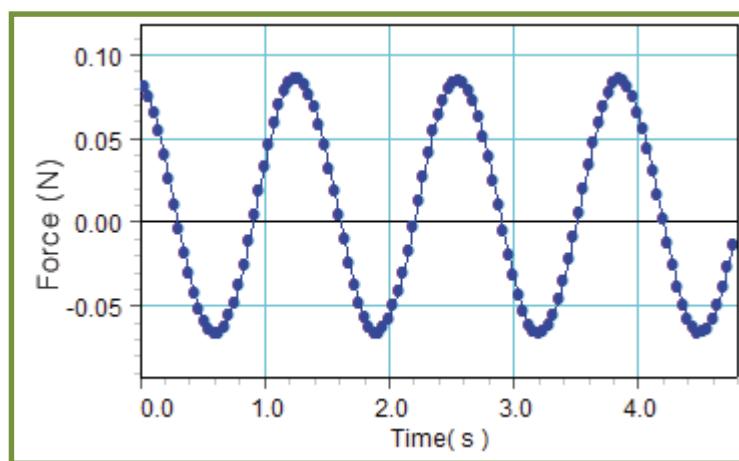
Applications

- Centripetal Force versus Velocity
- Centripetal Force versus Mass
- Centripetal Force versus Radius

How It Works

The rotating arm features a groove with two captured masses along its length. One of the masses is free to move along the length of the groove. The free mass is connected to a small cable that runs under a pulley in the center of the arm and up to a Force Sensor. A ball-bearing swivel is used to ensure the cable does not tangle as the arm rotates. The other mass is placed the same distance from the center as the free mass, thereby balancing the arm. A flag attached to the bottom of the fixed mass passes through the photogate once per revolution, allowing a calculation to be made of the angular and tangential velocity of the mass.

1x PASPORT High Resolution Force Sensor (PS-2189)



Product Summary

The PASPORT High Resolution Force Sensor offers a higher resolution than the PS-2104. It features a variable over-sampling rate that reduces measurement noise at lower sampling rates. The digital design minimizes drift, ensuring that the tare holds for hours. You can use this force sensor as a pan balance for long-

term experiments, such as investigating the evaporation of liquids, like alcohol or liquid nitrogen, and the sublimation of dry ice.

Features

- 0.002 N resolution
- Dynamic over-sampling
- Force overload protection up to 75 N
- Includes a receiver and thumbscrew for mounting
- Mounts to PASCO dynamics carts

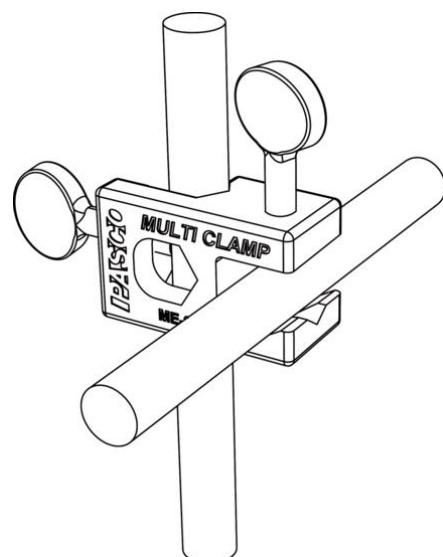
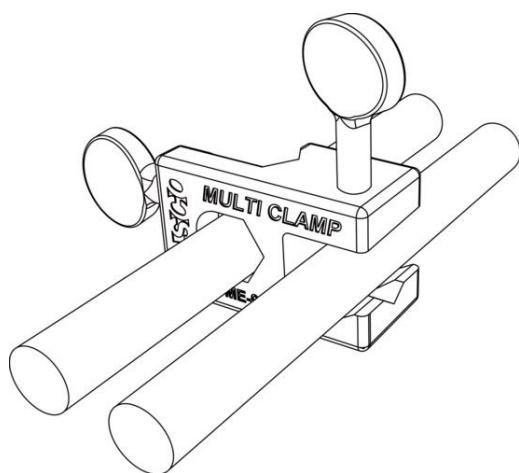
Applications

- Buoyant force
- Force exerted by an oscillating mass
- Force during elastic and inelastic collisions
- Centripetal force acting on a rotating object
- Force of a swinging pendulum
- Newton's Third Law, action and reaction forces
- Forces associated with static equilibrium

1x Multi-Clamp (ME-9507)

Product Summary: Holds two rods either parallel or at right angles. Fits rods up to 12.7 mm (1/2 inch) in diameter.

What's Included: 1x Clamp with two thumb screws



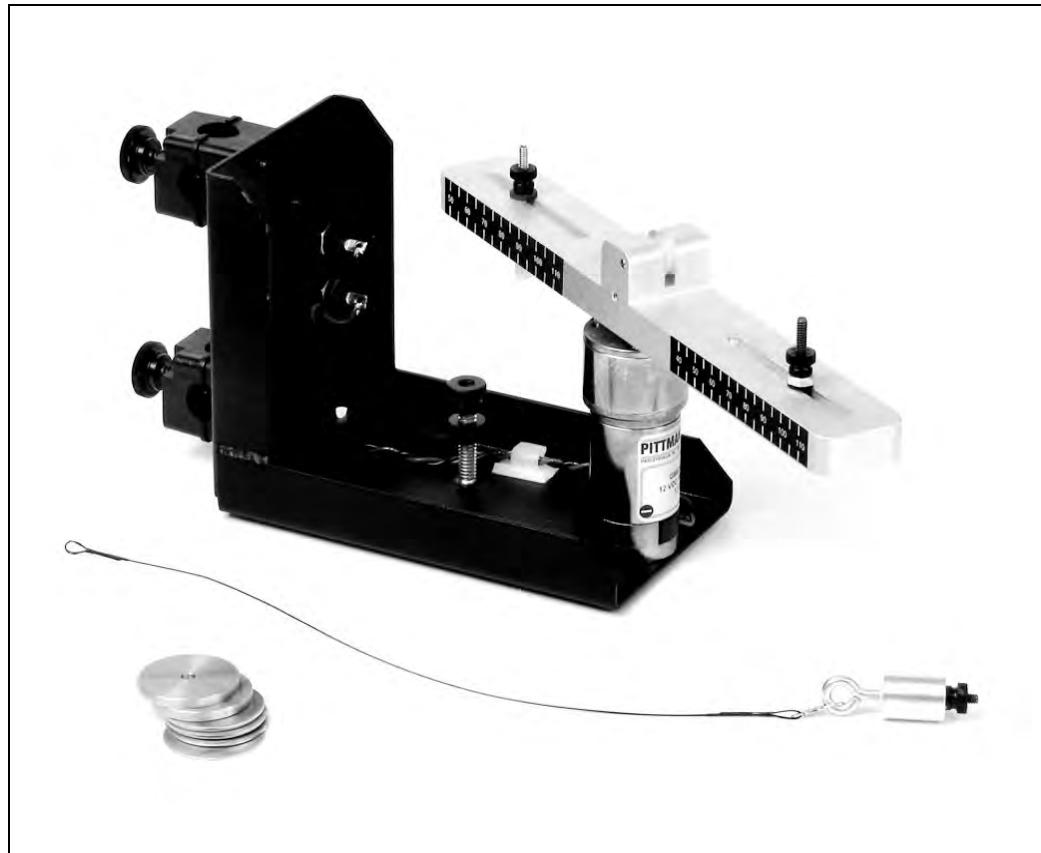


Instruction Manual

Manual No. 012-08478B

Centripetal Force Apparatus

Model No. ME-8088



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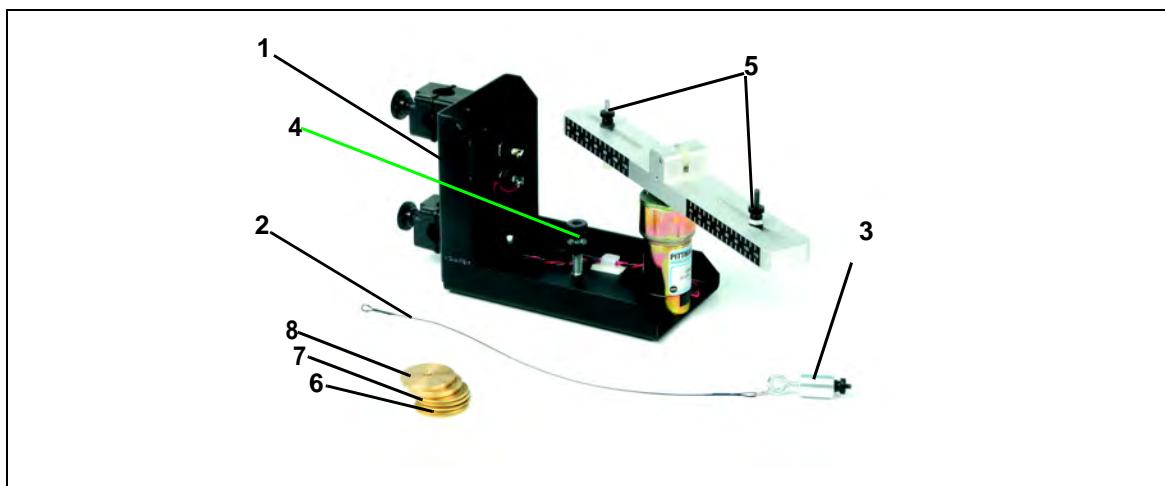
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Centripetal Force Apparatus

Model No. ME-8088

Equipment List



Included Equipment	Replacement Model Number*
1. Frame with Mounted Electric Motor (1)	NA
2. Connecting Cable (1)	623-038
3. Ball Bearing Swivel (1)	003-08383
4. Thumbscrew for Photogate (1)	614-034
5. Nuts for Free and Fixed Mass Holders (2)	614-029
6. 5 g Mass (2)	648-06507
7. 10 g Mass (2)	648-06508
8. 20 g Mass (2)	648-06509
9. Centripetal Force Apparatus Setup disk (3.5" floppy) (not shown above)	013-08478

*Use Replacement Model Numbers to expedite replacement orders.

NA = not available as individual replacement item. To replace product, use ME-8088.

(continued on next page)

Additional Equipment Recommended for Experiments (with <i>ScienceWorkshop</i>)	Replacement Model Number*
A computer (Windows or Macintosh)	NA
DataStudio® Software	various (see catalog)
<i>ScienceWorkshop</i> ® 500 or 750 Interface	CI-6400 or CI-6450 or CI-7650
Economy Force Sensor	CI-6746
Photogate Head	ME-9498A
Steel Rod (45 or 120 cm)	ME-8736 and ME-8741
Multi-Clamp	SE-9442
Large Rod Base	ME-8735
Banana plugs (1 red, 1 black)	SE-9750 or SE-9751
Triple Output Power Supply (12 V, 3 A) (1)	SE-8587

Additional Equipment Recommended for Experiments (with <i>PASPORT™</i>)	Replacement Model Number*
A USB-compatible computer (Windows or Macintosh)	NA
DataStudio Software (version 1.5 or later)	various (see catalog)
PASPORT™ Force Sensor	PS-2104
Photogate Port	PS-2123
Photogate Head	ME-9498A
USB Link (2) or Xplorer (2) or PowerLink	PS-2100 or PS-2000 or PS-2001
Steel Rod (45 or 120 cm)	ME-8736 and ME-8741
Multi-Clamp	SE-9442
Large Rod Base	ME-8735
Banana plugs (1 red, 1 black)	SE-9750 or SE-9751
Triple Output Power Supply	SE-8587

Introduction

PASCO's Centripetal Force Apparatus (ME-8088) allows students to investigate the relationships between centripetal force, radius, mass, and velocity for an object undergoing uniform circular motion. Traditional experiments in this area involve the swinging of masses above the head. The traditional approach is difficult to execute and data is rarely sufficient for an understanding of the relationships. The Centripetal Force Apparatus removes these difficulties by using sensors to measure the force and velocity of the mass as it rotates.

Velocity is varied by changing the voltage supplied to the included electric motor. Drilled masses are included to facilitate a range of mass trials. The radius is changed by sliding the captured masses along the grooves in the rotating arm. A convenient measuring scale is included on both sides of the arm.

The sturdy base includes rod clamps for connection to a standard rod stand or the unit can be clamped to a table using a common "C" clamp.



Figure 1: Setup with Force Sensor on stand

Equipment Setup

1. Mount a stainless steel rod into a base support stand.
2. Use the rod clamps to attach the Centripetal Force Accessory to the rod (See Figure 2).
3. Remove the free mass holder (Figure 3) and measure its mass. To remove the free mass holder, loosen the screw below the rotating arm.

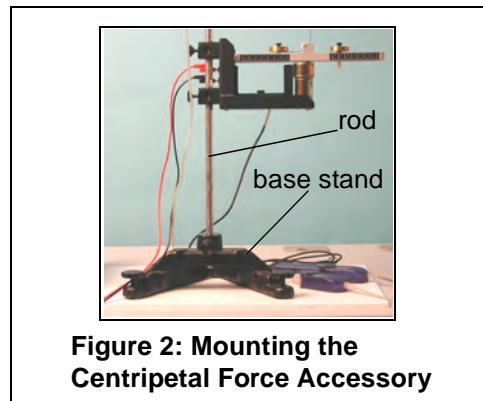


Figure 2: Mounting the Centripetal Force Accessory

(Note: The free mass holder includes the screw, two plastic washers, nut, and two thumbscrews. If a scale is not available, use the mass provided in Appendix A: Specifications.)



Figure 3: Free and Fixed Mass Holders

4. Use a thumbscrew to mount a Photogate Head (ME-9498A) to the bottom base of the Centripetal Force Accessory (See Figure 4).

5. Attach a Multi-Clamp to the upper end of the stainless steel rod. (Figure 5a).

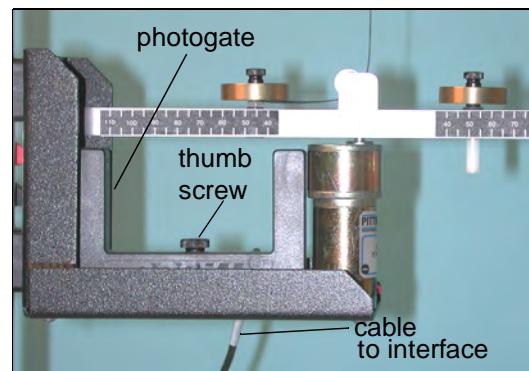


Figure 4: Photogate on base of Centripetal Apparatus

6. Insert another stainless steel rod horizontally into the Multi-Clamp.
7. Slide a Force Sensor through the stainless steel rod and adjust the top screw to anchor it to the rod (Figure 5a). (Note: Be sure to keep the cords from the sensor out of the path of the rotating arm.)

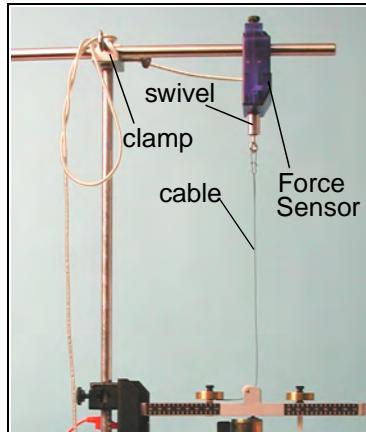


Figure 5a: Mounting the Force Sensor

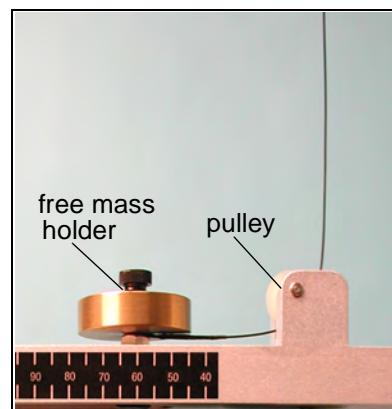


Figure 5b: Threading the cable through the free mass holder



Note: To calibrate the ScienceWorkshop Force Sensor, follow the instructions provided in the documentation included with your Force Sensor or in the DataStudio online help. Calibration of the PASPORT Force Sensor is not required. However, you can take the PASPORT Force Sensor by pressing the Zero button without any weight attached.

8. Attach the ball bearing swivel to the bottom of the Force Sensor
 9. Thread the cable from the swivel hook through the pulley and over the free mass holder (Figure 5b).
- Note:** Always lay down the cable *before* adding the mass.
10. Add a mass to the free mass holder; then screw on the thumbscrew to hold the mass in place.
 11. Add a mass to the fixed mass holder and use a thumbscrew to hold the mass in place.
 12. Plug the Force Sensor into either a PASPORT or ScienceWorkshop interface.

13. Use banana plugs to connect the Centripetal Force Accessory to a Power Supply.

14. To turn on the motor to the Centripetal Force Accessory, turn on the Power Supply.

(CAUTION: To avoid damaging the equipment, keep all cords away from the motor and rotating arm.)

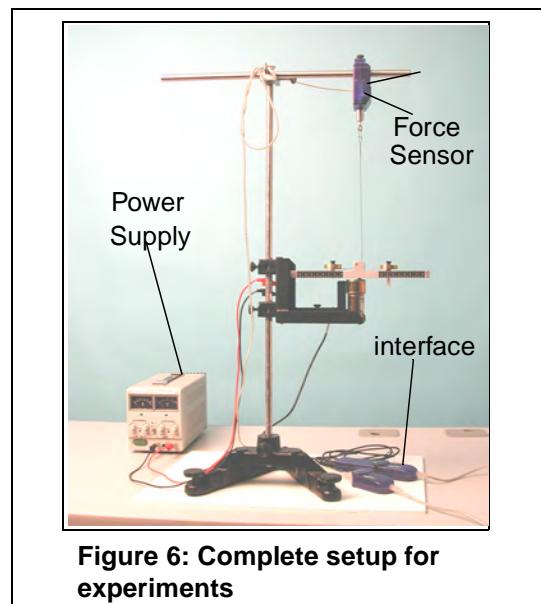


Figure 6: Complete setup for experiments



WARNING: Do not stand next to the motor or rotating arm or look at the rotating arm at eye level. To avoid possible injury from the rotating arm hitting the body, keep at least 1 foot distance from the motor and rotating arm when running the motor.



Note: If you do not have a setup disk available, follow the DataStudio setup instructions in Appendix B (for PASPORT sensors) or C (for ScienceWorkshop sensors).

Suggested Experiments

Experiment 1: Centripetal Force vs. Velocity

Equipment Required (for use with <i>ScienceWorkshop</i> sensors):	Equipment Required (for use with <i>PASPORT</i> sensors):
<i>ScienceWorkshop</i> Force Sensor (CI-6746)	<i>PASPORT</i> Force Sensor (PS-2104)
Photogate Head (ME-9498A)	Photogate Head (ME-9498A)
<i>ScienceWorkshop</i> interface (500, 700, or 750) (CI-6400 or CI-6450)	Photogate Port (PS-2123)
Power Supply (12 v, 3A) (SE-8587)	USB Link (2) (PS-2100) or Xplorer (2) (PS-2000) or Power Link (PS-2001)
DataStudio Software (ver. 1.5 or higher)	Power Supply (12 V, 3AA) (SE-8587)
Base support, clamps, and mounting rods	DataStudio Software (ver. 1.5 or higher)
	Base support, clamps, and mounting rods

Introduction

In this experiment, you will *vary the velocity* by changing the voltage to the electric motor as the centripetal force is continuously measured by the Force Sensor. The radius and mass are held constant as the velocity is increased.

Setup

Follow the equipment setup instructions on pages 5-7 of this manual and the Experiment Tips that follow. When you are ready to begin the experiment, open the appropriate DataStudio file on the setup disk.

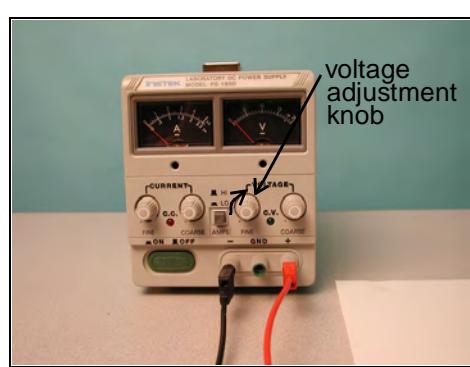


Figure 1a: Adjusting the voltage on the Power Supply

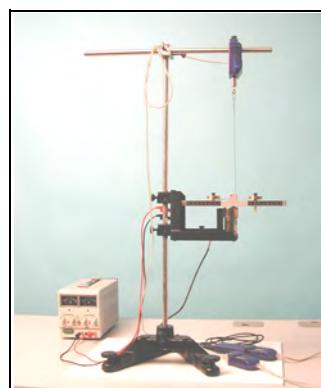


Figure 1b: Complete setup



Note: If you do not have a setup disk available, follow the DataStudio setup instructions in Appendix B (for *PASPORT* sensors) or C (for *ScienceWorkshop* sensors).

Experiment Tips

- a) To add the free mass, lay the components over the attachment screw in the following order: a) cable b) mass and c) thumbscrew to tighten.
 (Note: Place the cable over the washer and nut on the screw. For more details, see "Equipment Setup" on pages 5-7.)

Note: Do not place the mass underneath the cable, as this will interfere with a proper measurement.

- b) Allow the "free mass" plenty of length along its holder within the slot. If the mass is not free to slide along the groove, significant frictional losses can be present.
- c) Place an equal amount of mass on the "fixed mass" and "free mass" holders.
- d) Be sure to place the "fixed mass" at the same radius as the "free mass" to ensure balancing of the unit as it rotates.
- e) The velocity of the free mass can be measured as an angular or linear velocity. DataStudio files for both of these variations are included on the floppy disk.
- f) Be sure to enter the correct value for the radius in the experimental constants area of the calculator (when using the linear velocity DataStudio file).

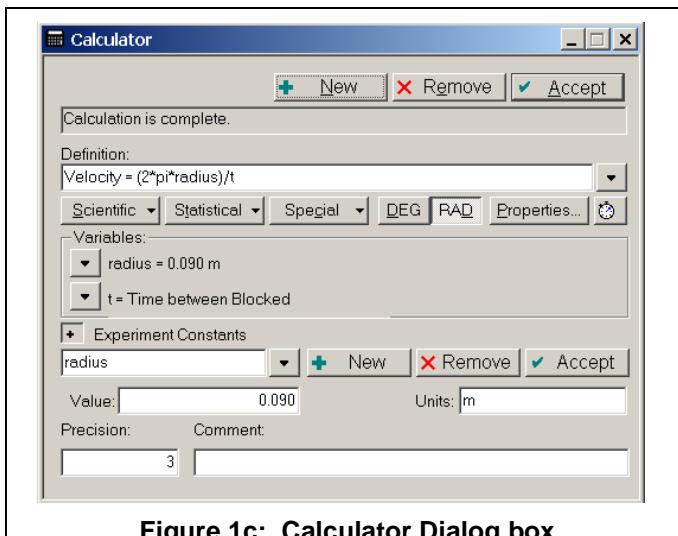


Figure 1c: Calculator Dialog box

Experiment 2: Centripetal Force vs. Mass

Equipment Required (for use with ScienceWorkshop sensors):	Equipment Required (for use with PASPORT sensors):
ScienceWorkshop Force Sensor (CI-6746)	PASPORT Force Sensor (PS-2104)
Photogate Head (ME-9498A)	Photogate Head (ME-9498A)
ScienceWorkshop interface (500, 700, or 750) (CI-6400 or CI-6450)	Photogate Port (PS-2123)
Power Supply (12 v, 3A) (SE-8587)	USB Link (2) (PS-2100) or Xplorer (2) (PS-2000) or Power Link (PS-2001)
DataStudio Software (ver. 1.5 or higher)	Power Supply (12 V, 3AA) (SE-8587)
Base support, clamps, and mounting rods	DataStudio Software (ver. 1.5 or higher)
	Base support, clamps, and mounting rods

Introduction

In this experiment, the radius and velocity are held constant as the *mass is varied*. By adding additional drilled masses to the holder, the mass of the system is increased. Equal amounts of mass must also be added to the “fixed mass” to balance the arm as it rotates. Centripetal force is directly measured by the Force Sensor.

Setup

Follow the equipment setup instructions on pages 5-7 of this manual and the Experiment Tips below. When you are ready to begin the experiment, open the appropriate DataStudio file on the setup disk.

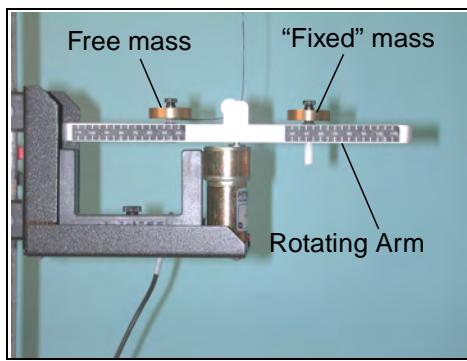


Figure 2a: Free and fixed Mass Holders

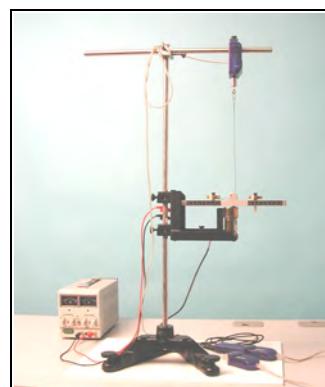


Figure 2b: Complete setup



Note: If you do not have a setup disk available, follow the DataStudio setup instructions in Appendix B (for PASPORT sensors) or C (for ScienceWorkshop sensors).

Experiment Tips

- a) To add the free mass, lay the components over the attachment screw in the following order: a) cable b) mass and c) thumbscrew to tighten.
 (Note: Place the cable over the washer and nut on the screw. For more details, see “Equipment Setup” on pages 5-7.)

Note: Do not place the mass underneath the cable, as this will interfere with a proper measurement.

- b) Allow the “free mass” plenty of length along its holder within the slot. If the mass is not free to slide along the groove, significant frictional losses can be present.
- c) Place an equal amount of mass on the “fixed mass” and “free mass” holders.
- d) Be sure to place the “fixed mass” at the same radius as the “free mass” to ensure balancing of the unit as it rotates.
- e) Perform several different data runs, each time varying the mass on the free and fixed mass holders. (**Note:** Be sure to include the mass of the holders in your calculations.)
- f) In the DataStudio file for this experiment, a graph display is available for monitoring the velocity of the rotating mass.
- g) Be sure to enter the correct value for the radius in the experimental constants area of the calculator.

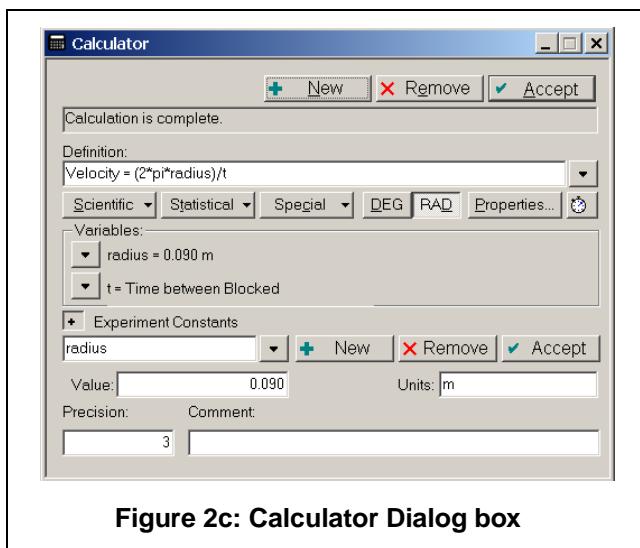


Figure 2c: Calculator Dialog box

Experiment 3: Centripetal Force vs. Radius

Equipment Required (for use with <i>ScienceWorkshop</i> sensors):	Equipment Required (for use with PASPORT sensors):
<i>ScienceWorkshop</i> Force Sensor (CI-6746)	PASPORT Force Sensor (PS-2104)
Photogate Head (ME-9498A)	Photogate Head (ME-9498A)
<i>ScienceWorkshop</i> interface (500, 700, or 750) (CI-6400 or CI-6450)	Photogate Port (PS-2123)
Power Supply (12 v, 3A) (SE-8587)	USB Link (2) (PS-2100) or Xplorer (2) (PS-2000) or Power Link (PS-2001)
Base support, clamps, and mounting rods	Power Supply (12 V, 3AA) (SE-8587)
DataStudio Software (ver. 1.5 or higher)	Base support, clamps, and mounting rods
	DataStudio Software (ver. 1.5 or higher)

Introduction

In this experiment, the velocity and mass are held constant as the *radius is varied*. By lowering the Force Sensor, the radius increases. As the radius increases, the “fixed mass” must be moved to a matching radius to balance the rotating arm. Again, centripetal force is measured by the Force Sensor.

Setup

Follow the equipment setup instructions on pages 5-7 of this manual and the Experiment Tips that follow. When you are ready to begin the experiment, open the appropriate DataStudio file on the setup disk.

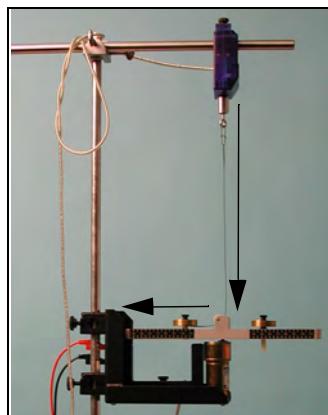


Figure 3a: Changing the radius

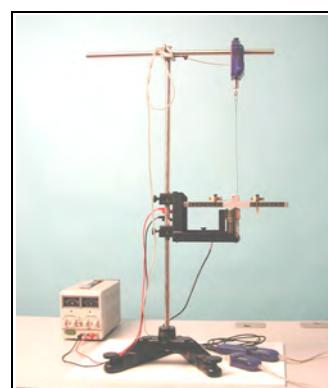


Figure 3b: Complete setup



Note: If you do not have a setup disk available, follow the DataStudio setup instructions in Appendix B (for PASPORT sensors) or C (for ScienceWorkshop sensors).

Experiment Tips

- a) Allow the “free mass” plenty of length along its holder within the slot. If the mass is not free to slide along the groove, significant frictional losses can be present.
- b) To add the free mass, lay the components over the attachment screw in the following order: a) cable b) mass and c) thumbscrew to tighten. (Note: Place the cable over the washer and nut on the screw. For more details, see “Equipment Setup” on pages 5-7.)

Note: Do not place the mass underneath the cable, as this will interfere with a proper measurement.

- c) Place an equal amount of mass on the “fixed mass” and “free mass” holders.
- d) Be sure to place the “fixed mass” at the same radius as the “free mass” to ensure balancing of the unit as it rotates.
- e) To vary the radius, adjust the position of the Force Sensor (See Figure 3a).
- f) In the DataStudio file for this experiment, a graph display is available for monitoring the velocity of the rotating mass.
- g) Be sure to enter the correct value for the radius in the experimental constants area of the calculator. This will need to be changed for each data run of this experiment.

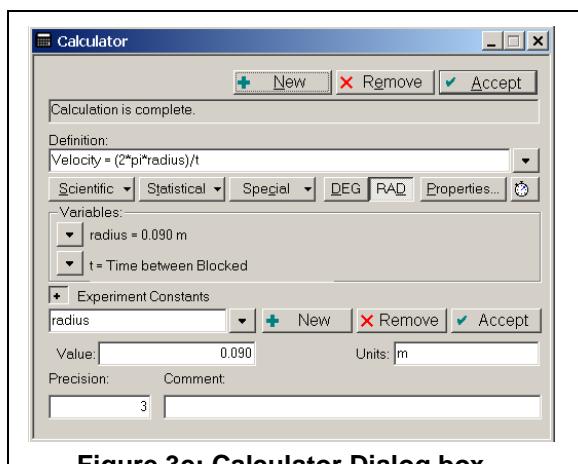
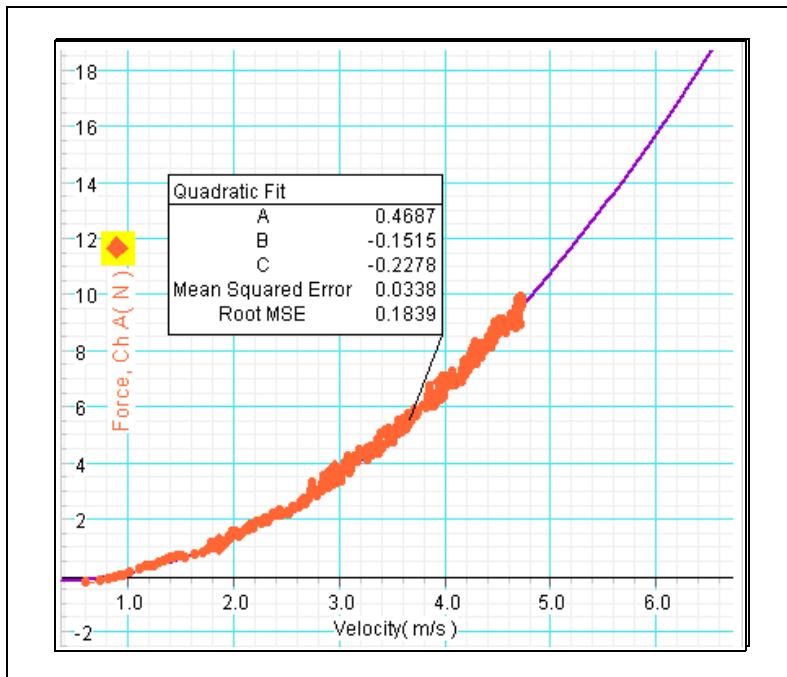


Figure 3c: Calculator Dialog box

Sample Data



Troubleshooting

Problem:	Possible Causes:	Possible Solutions:
Rotating arm does not move.	Too much friction in the cable; power supply is not turned on; motor is defective.	Move Force Sensor down to loosen the cable; connect the power supply to the frame and turn on the power supply; call Technical Support and/or return the product (See Warranty information in Appendix E.)
Force measurement does not display in DataStudio.	Force Sensor is not connected to an interface or associated in the setup window.	If using a PASPORT Force Sensor, plug the Force Sensor into a USB Link connected to a USB-compatible computer. Follow the setup instructions in Appendix B. If using a <i>ScienceWorkshop</i> Force Sensor, connect the Force Sensor to a <i>ScienceWorkshop</i> interface. Follow the setup instructions in Appendix C.
Velocity readings do not appear or are incorrect.	Photogate is not connected to an interface; improper setup in DataStudio.	If using a PASPORT interface, click the Setup button , click the Add Timer button , and select the Smart Pulley option. If using a <i>ScienceWorkshop</i> interface, click the Setup button and select the Smart Pulley option from the Sensors list.

Appendix A: Specifications

Centripetal Force Apparatus	
Rotating Arm	Length: 24.6 cm
Motor	12 VDC, 0.5 ampere
Frame	Base: 15 x 8.5 cm Back: 11.5 x 8.5 cm Mass (with motor, cable, and rotating arm): 2.10 kg
Free Mass Holder	4.0 g (with screws)
Fixed Mass Holder	2.5 g (with screws)
Thumbscrew	0.5 g
Masses	5 g, 10 g, 20 g
Ball Bearing Swivel	Mass: 12.5 g

Appendix B: DataStudio Setup Instructions (for PASPORT interfaces)

The following instructions are for new users or those unfamiliar with DataStudio software.

PART I: Plug the sensors into the PASPORT interface:

- a) Plug the Photogate into either channel 1 or 2 on a PASPORT Photogate Port.
- b) Plug both the Photogate Port and Force Sensor into a PASPORT interface (i.e. USB Link, Xplorer, PowerLink, etc.).

PART II: Set up your experiment in DataStudio

- a) Open DataStudio and select “Create Experiment.”
- b) On the main toolbar, click the **Setup** button to open the Experiment Setup window.
- c) When the Experiment Setup dialog opens, click on the **Add Timer** button, select the Recordable Timer icon, and click OK.

PART III: Create a recordable timing sequence in DataStudio

- a) Click the **Record Sequence** button in the Experiment Setup window.
- b) In the Record Timer Sequence box, click the **Start** button.
- c) Block the beam of the photogate twice with your finger, and click the **Stop** button.
- d) In the Record Timer Sequence box, highlight “Photogate 1 unblocked,” and click the **Delete** button. (Repeat this task for the second “Photogate 1 unblocked.”)
- e) Click the **OK** button to accept the timing sequence.

PART IV: Create the mathematical equation in DataStudio

- a) Click on the **Calculate** button to open the Calculator dialog.
- b) In the Calculator dialog, click the **New** button to create a new equation.
- c) In the equation box, type in the equation $velocity = 2\pi * radius / t$ and click the **Accept** button.
- d) Define the variables “radius” and “t.” (Under Variables, click on the arrow and select “constant” to define the variable “radius” and enter the value in the box. Under “Experiment Constants,” click the **Accept** button. Select “Data Measurement” for “t” and select “time between gates.”)
- e) Click the Accept button. Your equation will appear as an icon in the Data list. To edit the equation, double click on the equation icon in the Data list.

PART V: Collect data

- a) To collect data in a display, click the **Start** button.

Appendix C: DataStudio Setup Instructions (for *ScienceWorkshop* interfaces)

PART I: Plug the sensors into the interface:

- a) Plug the Photogate into channel 1 on the *ScienceWorkshop* interface.
- b) Plug the Force Sensor into any analog channel (A, B, or C) on the *ScienceWorkshop* interface.

PART II: Set up your experiment in DataStudio

- a) Open DataStudio and select “Create Experiment.”
- b) On the main toolbar, click the **Setup** button to open the Experiment Setup window.
- c) In the Sensors list of the Experiment Setup window, do the following: i) Click on the Smart Pulley icon and drag it to digital channel 1 on the picture of the interface. ii) Click on the Force Sensor icon and drag it to the same analog channel into which the sensor is plugged.

Part III: Create a timing sequence in DataStudio

- a) On the main toolbar, click the **Timers** button. When the Timers dialog opens, click the **New** button.
- b) In the Label box, type the name, “time between blocked.”
- c) In the Timing Sequence menu, select “blocked” and “blocked” and click **OK**.

PART IV: Create the mathematical equation in DataStudio

- a) Click on the **Calculate** button to open the Calculator dialog.
- b) In the Calculator dialog, click the **New** button to create a new equation.
- c) In the equation box, type in the equation $velocity = 2\pi * radius / t$ and click the **Accept** button.
- d) Define the variables “radius” and “t.” (Under Variables, click on the arrow and select “constant” to define the variable “radius” and enter the value in the box. Under “Experiment Constants,” click the Accept button. Select “Data Measurement” for “t” and select “time between blocked.”)
- e) Click the Accept button. Your equation will appear as an icon in the Data list. To edit the equation, double click on the equation icon in the Data list.

PART V: Collect data

- a) To collect data in a display, click the **Start** button.

Appendix D: Technical Support

For assistance with the ME-8088 Centripetal Force Apparatus or any other PASCO products, contact PASCO as follows:

Address: PASCO scientific

10101 Foothills Blvd.

Roseville, CA 95747-7100

Phone: (916) 786-3800

FAX: (916) 786-3292

Web: www.pasco.com

Email: techsupp@pasco.com

Appendix E: Copyright and Warranty Information

Copyright Notice

The PASCO scientific 012-08478B *Centripetal Force Manual* is copyrighted and all rights reserved. However, permission is granted to non-profit educational institutions for reproduction of any part of the 012-08478B *Centripetal Force Manual*, providing the reproductions are used only for their laboratories and are not sold for profit. Reproduction under any other circumstances, without the written consent of PASCO scientific, is prohibited.

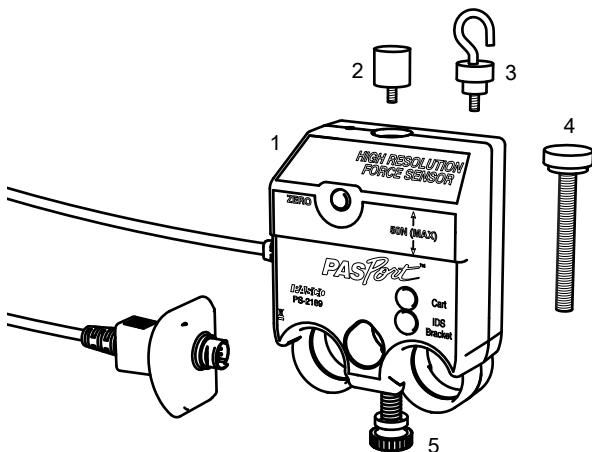
Limited Warranty

PASCO scientific warrants the product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. The warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific.

Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment after repair will be paid by PASCO scientific.

High Resolution Force Sensor

PS-2189



Included Parts

1. High Resolution Force Sensor
2. Bumper attachment
3. Hook attachment
4. Cart/Bracket thumbscrew (M5 x 45 mm)
5. Rod clamp thumbscrew (1/4-20 x 0.75 inch)

Additional Items Required

- PASPORT interface
- PASCO Data Collection Software

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

www.pasco.com

Quick Start

1. Connect the High Resolution Force Sensor to your PASPORT interface.
2. Connect the PASPORT interface to the computer and start the data collection software.
3. Screw the hook attachment into the sensor.
4. Press or click the start button to begin recording data.

5. Push or pull the hook. The sensor measures the applied force.

Introduction

The High Resolution Force Sensor connects to a PASPORT interface and records force in the range of -50 N to +50 N at a rate of up to 1000 samples per second. High resolution, dynamic over-sampling, and a low drift rate make the sensor well suited for measuring very small changes

Set-up

Connecting the Sensor to an Interface

1. Connect the sensor's plug to any port of a PASPORT interface.
2. If you are using a computer, connect the PASPORT interface to it and start the data collection software.

Software Setup

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.

Zeroing the Sensor

Press the ZERO button on the sensor. The sensor's output is adjusted to read zero.

SPARKvue

Collect Data

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

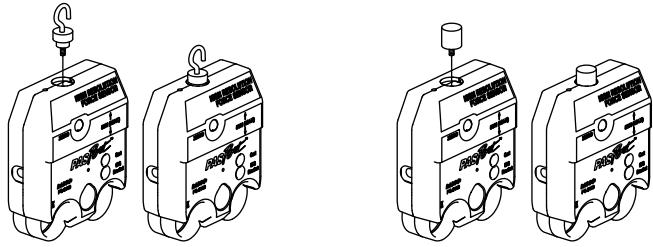
PASCO Capstone

Collect Data

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

Connecting Bumper and Hook Attachments

Screw the bumper or hook into the sensor as illustrated.



About the Force Measurement

Dynamic Over-sampling

To increase the degree of dynamic over-sampling, lower the sample rate.

Over-sampling reduces noise, produces smoother data, and improves the measurement resolution. This effect is especially noticeable when very small force changes are measured. The degree of over-sampling depends on the sample rate. Maximum over-sampling occurs at sample rates of 20 Hz and slower.

Sample Rate

By default, the sensor collects 10 samples per second. It can collect data as fast as 1000 samples per second and as slow as one sample every four hours. Change the sample rate in the data collection software.

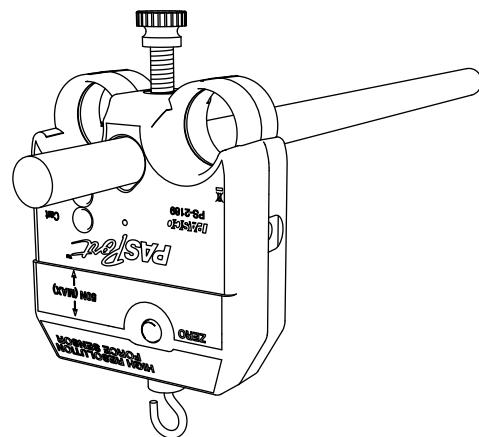
Inverted Output

By default, the sensor registers pushing as a positive force and pulling as a negative force. To register pulling as positive and pushing as negative, select the **Force (Inverted)** measurement in the data collection software.

Sensor Mounting

Mounting the Sensor on a Rod

Slide the sensor onto a rod and secure it with the thumbscrew as illustrated.



Mounting the Sensor on a PASCO Cart

1. Insert the included Cart/Bracket thumbscrew through the hole in the sensor labeled **Cart**.
2. Screw the thumbscrew into the threaded hole on the top of the cart.

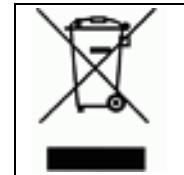
Mounting the Sensor on an IDS Bracket

1. Insert the included Cart/Bracket thumbscrew through the hole in the IDS Force Accessory Bracket (PASCO part CI-6545).
2. Screw the thumbscrew into the hole in the sensor labeled **IDS Bracket**.

Specifications

Range	±50 N
Resolution	0.002 N
Maximum Sample Rate	1000 samples/s

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.



Technical Support

For assistance with any PASCO product, contact PASCO at:

Address:	PASCO scientific 10101 Foothills Blvd. Roseville, CA 95747-7100
Phone:	916-786-3800 (worldwide) 800-772-8700 (U.S.)
Web:	www.pasco.com
Email:	support@pasco.com

For more information about the High Resolution Force Sensor and the most up-to-date version of this Instruction Sheet, visit:

www.pasco.com/manuals

Limited Warranty

For a description of the product warranty, see the PASCO catalog.

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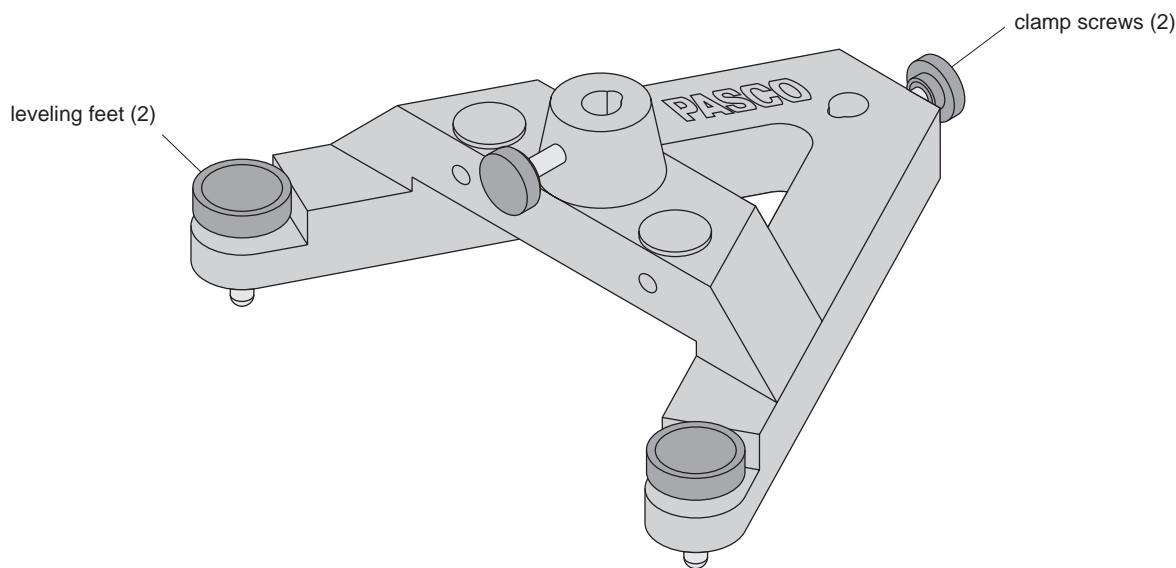
www.pasco.com/legal.

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.

**Instruction Sheet
for the PASCO
Model ME-8735**

Large Rod Stand



Introduction

The PASCO Model ME-8735 Large Rod Stand can be used whenever a sturdy base for your vertical support rod is needed.

Rods with an outside diameter of 1/4" to 1/2" (6.5mm to 13mm) may be placed in either the central mounting hole and/or the alternate mounting hole at the peak of the stand. They can be secured to the stand with either of the two clamp screws provided.

The Large Rod Stand can be leveled by turning the knobs on the leveling feet.

When using the Large Rod Stand keep the following in mind:

- ① The mass of the Large Rod Stand is approximately 9 lbs. (4 kg). If dropped, the Large Rod Stand may be damaged, cause damage to other equipment or cause injury. To prevent personal injury and damage, always carry the Large Rod Stand with a firm grip and try to setup the Large Rod Stand away from the edge of any table or work bench whenever possible.
- ② To prevent the Large Rod Stand from tipping or toppling over during experiments, be reasonable as you setup experiments. Always be sure the Large Rod Stand is able to rest firmly when any possible motion of your experiments occur.

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This instruction sheet written/edited by: Eric Ayars

Equipment Included

One ME-8735 Large Rod Stand complete with two leveling feet and two clamp screws.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

Equipment Return

Should the product have to be returned to PASCO scientific for any reason, notify PASCO scientific by letter, phone, or fax BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

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

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

- ① The packing carton must be strong enough for the item shipped.
- ② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.
- 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.

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

Phone: (916) 786-3800
FAX: (916) 786-3292
email: techsupp@asco.com
web: www.pasco.com