1. Purpose

To use a PASCO apparatus containing a rotating brass object to confirm Newton’s Second Law of rotation by varying the following parameters:

1. the radius of the brass object
2. the theoretical centripetal force (i.e. hanging mass) on the brass object
3. the mass of the brass object

while all other parameters, except for the period of rotation, remain constant.

2. Theory

By Newton’s Second Law, the force that produces uniform circular motion, or the centripetal force is given by $F_{NET} = \frac{Mv^2}{r}$, where $M$ is the mass being rotated, $v$ is its tangential velocity, and $r$ is the radius of the circular motion. As it stands, mass and radius are easy to measure, but the tangential velocity is not. However, we know that $v = r\omega$ for objects in uniform circular motion, and we know that $\omega = 2\pi/T$, where $\omega$ is the angular velocity and where $T$ is the period of revolution. Now, you need to determine the new centripetal force equation by substituting $\omega = 2\pi/T$ into $v = r\omega$ and then substitute the result into $F_{NET} = \frac{Mv^2}{r}$. Write the centripetal force equation in the box to the right.

Equation (1) will be used in the analysis as it contains easily measurable quantities: mass, radius and period. By varying the radius, the centripetal force and the mass, we can study the various effects on the rotating object.

3. Equipment

Rotating platform assembly
(1) 300 g or greater, square, black mass (for purposes of leveling only)
ME-8952 Centripetal Force Assembly
- Center post assembly
  o Center post
  o Spring bracket
  o Spring with attached orange indicator disk
  o Thumbscrew
  o Center post should have pulley, thumbscrew and indicator bracket pre-attached
- Side post assembly
  o Nylon thumbscrew
  o Thumbscrew mount
Equipment (continued)
  - Black thread
  - Brass mass (~200 g) with 3 hooks on edges (may be separated into a 100 g brass mass and two 50 g brass side masses).
  - Hanging mass holder with 3-5 individual 10g masses
  - Clamp-on Pulley
  - Stopwatch
  - Balance

Equipment Setup:

The Centripetal Force experiment requires that the rotating platform assembly be extremely level. If it is not level, the experimental results will be wildly different from the theoretical results.

**Leveling the Rotating platform**

1. Attach the 300g black, square mass (or greater mass, up to 1kg) to the END of the rotating platform track. Let the platform rotate until it comes to rest, at that point it will be at its “low” spot. Then slowly adjust one of the screws [preferably the one farthest from the rotating platform] until the track is aligned over the OTHER screw.

2. At this time the platform should be perpendicular to one side of the “A” shaped base. Rotate the platform 90 degrees; it should be parallel with one side of the “A” shaped base. Now, adjust the OTHER leveling screw (the screw you DID NOT turn in step 1) until the platform stays in the position that you originally set it at (i.e. the position in italics above).

3. Now, check to see that the track (platform) is level and no matter which way you orient the platform, it should not rotate under its own power.

**ONCE LEVEL, DO NOT MOVE THE BASE OF YOUR APPARATUS!**
The following two sets of instructions (in bold type) MIGHT need to be done depending on the state of your particular setup. It is not necessary to undo the already prepared post assemblies and redo them UNLESS the assembly is in sad disarray.

**Center Post Assembly (See Figure 5.)** [MIGHT need to be done]
1. Attach one end of the spring to the spring bracket and connect the indicator disk to the other end of the spring. Insert the spring bracket into the slot on the center post and tighten the thumbscrew.
2. Tie one end of a string (approximately 30 cm, you don’t want it to be too short) to the bottom of the indicator disk and tie a loop in the other end of the string.
3. Insert the indicator bracket into the slot on the center post, placing it below the spring bracket. Tighten its thumbscrew.
4. Attach the pulley to the center post, placing it in the third hole from the bottom.
5. Insert the thumbscrew at the bottom of the center post and attach the square nut.

![Figure 5: Center Post Assembly](image)

**Side Post Assembly (See Figure 6.)**
1. Insert the thumbscrew at the bottom of the side post and attach the square nut.
2. Using a string (approximately 30 cm long, it may need to be longer to make it easier to attach), tie the string around the screw head on the top of the side post. Then thread the other end of the string down through one of the holes in the top of the side post and then back up through the other hole. Do not pull the string taut.
3. Loosen the screw on the top of the side post and wrap the loose end of the string around the threads of the screw and tighten the screw.

**Threading the Centripetal Force Accessory (See Figure 7.)**
1. Mount the center post in the T-Slot on the side of the track that has the rule. If you do not put it on the side with the rule, the posts will rotate on the thumbscrew. The ruled side has a lip that stops the posts from rotating. Align the reference dot on the center post with the zero mark on the rule and tighten the thumbscrew to secure it in place. Then mount the side post on the same side of the track. When you look at the center post head on, the pulley should be offset toward the left.
2. Hang the brass mass (only the 100 portion) from the string on the side post and adjust the height of the mass so the string coming from the center post, around the pulley, will be level. See figure 4 above.
Note: The string should be coming directly through the center of the indicator bracket. If it is not, the side post is on the wrong side.

4. Procedure/Analysis

You will be performing 3 separate experiments with the rotating brass object. The first will be to vary the radius of rotation of the brass object, the second will be to vary the measured centripetal force (i.e. hanging mass) on the brass object and the third will be to vary the mass of the brass object while all other parameters remain constant except the period of rotation.

It is strongly recommended that you use an Excel spreadsheet set-up similar to the tables seen below, as the program will quickly and accurately perform your calculations for Part I, II and III. Ask your professor to show you how to use Excel if you are not familiar with it.

Part I: Vary Radius (which will result in the period varying)

1. The hanging mass and the mass of the brass object will be kept constant for this part. Weigh the brass object (use the ~100 g portion) and record its mass. Hang the brass object from the side post and connect the string from the spring to the object. The string must pass under the pulley on the center post.
2. Attach the clamp-on pulley to the end of the track nearer to the brass object. Attach a string to the hook in the brass object and hang the mass holder with a known amount of mass over the clamp-on pulley. This string must be perfectly horizontal between the clamp-on-pulley and side post and recall the string between the side and center post must also be perfectly horizontal! Decide on a mass to hang on the weight hanger, and place hanger with masses on the string hanging over the clamp-on-pulley. Weigh and record this
hanging mass plus the mass of the weight hanger, as its weight will equal the constant centripetal force.

3. Select a radius by aligning the line on the side post with any position on the rule. While pressing down on the side post to assure that it is vertical, tighten the thumbscrew. Make sure that there is some tension in the spring and a bit of room for the spring bracket and the indicator bracket to move up and down. Record this radius.

4. The *brass object on the side post must hang vertically*, which means that the string must be aligned with the line on the side post. On the center post, adjust the spring bracket vertically until the string from which the object hangs on the side post is aligned with the line on the side post.

5. Align the indicator bracket on the center post with the indicator disk. This must be done BEFORE you remove the hanging mass from the system.

6. Remove the hanging mass and the clamp-on-pulley from the system. It is *okay* that the orange indicator disk will move away from the indicator bracket and some strings will no longer be perfectly vertical or horizontal.

7. Rotate the apparatus using the knurled section on the rotating base, increasing the speed until the indicator disk is aligned in the indicator bracket on the center post. This indicates that the string supporting the brass object is vertical and thus the hanging object is at the desired radius and should have the constant centripetal force equal to the hanging weight.

8. You must maintain the rotational velocity by supplying force (torque) to the knurled section on the rotating base. Keep an eye on the indicator disk and make sure that it does not deviate from the confines of the indicator bracket. Once a constant rotational velocity has been attained, use a stopwatch to time ten revolutions. Make sure you count 10 complete revolutions. It is best to have one person maintain the velocity and another count and operate the stopwatch. Divide the time by ten and record the period.

9. Move the side post to a new radius and repeat the procedure. You will have to reattach the hanging mass (the centripetal force must remain constant for this entire part) and you may have to adjust the indicator bracket and/or the spring bracket. Do this for a total of 3 radii.

**Analysis and Results for Part I:**

1. **The weight of the hanging mass is equal to the centripetal force applied to the brass object, in order to keep it balanced against the spring tension or at the original radius while turning.** Make sure you understand WHY (using physical principles) the previous sentence is true! **Ask your instructor to confirm that your logic is correct.** Calculate the actual centripetal force by multiplying the hanging mass (+ weight hanger) by the gravitational acceleration constant, \( g \), and record this value.

2. Calculate the square of the period for each radius and record. Using eqn (1) from above, calculate the experimental centripetal force applied to the brass object. Note: the \( M \) here is the mass of the brass object. The hanging mass has already been used to calculate your theoretical centripetal force. Record the experimental centripetal force for each radius.

3. Calculate the percentage difference between the theoretical centripetal force and the experimental centripetal force for each radius.
Sample Data:

<table>
<thead>
<tr>
<th>Hanging Mass + weight hanger, m (g)</th>
<th>Brass Object, M (g)</th>
<th>Radius (m)</th>
<th>Period, T (s)</th>
<th>$T^2$ (s²)</th>
<th>Theoretical Centripetal Force, mg (N)</th>
<th>Experimental Force (eqn 1) (N)</th>
<th>% Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.4</td>
<td>208.7</td>
<td>.160</td>
<td>1.643</td>
<td>2.700</td>
<td>.494</td>
<td>.488</td>
<td>1.1 %</td>
</tr>
<tr>
<td>50.4</td>
<td>208.7</td>
<td>.192</td>
<td>1.790</td>
<td>3.204</td>
<td>.494</td>
<td>.494</td>
<td>0.0 %</td>
</tr>
<tr>
<td>50.4</td>
<td>208.7</td>
<td>.223</td>
<td>1.922</td>
<td>3.694</td>
<td>.494</td>
<td>.497</td>
<td>0.7 %</td>
</tr>
</tbody>
</table>

Part II: Vary Hanging Mass, i.e. Actual Centripetal Force (which will result in varying the period)

1. The **radius of rotation and the mass of the brass object will be held constant for this part** of the experiment. Weigh the brass object again and record its mass. Hang the brass object from the side post and connect the string from the spring to the object, as before.

2. Attach the clamp-on-pulley to the end of the track nearest the side post. Attach a string to the brass object and hang a known, measured mass over the clamp-on pulley. Record this hanging mass (including the mass of the weight hanger).

3. Select a radius by aligning the line on the side post with any position on the rule. While pressing down on the side post to assure that it is vertical, tighten the thumbscrew. Make sure that there is some tension in the spring and a bit of room for the spring bracket and the indicator bracket to move up and down. Record this radius.

4. The brass object on the side post must hang vertically, which means that the string must be aligned with the line on the side post. On the center post, adjust the spring bracket vertically until the string from which the brass object hangs on the side post is aligned with the line on the side post (i.e. it must be perfectly vertical).

5. Align the indicator bracket on the center post with the orange indicator disk. This must be done **BEFORE** you remove the hanging mass from the system.

6. Remove the hanging mass and the clamp-on-pulley from the system. It is **okay** that the orange indicator disk will move away from the indicator bracket and some strings will no longer be perfectly vertical or horizontal.

7. Rotate the apparatus using the knurled section on the rotating base, increasing the speed until the indicator disk is aligned in the indicator bracket on the center post. This indicates that the string supporting the brass object is vertical and thus the hanging object is at the desired radius and should have the centripetal force equal to the hanging weight.

8. You must maintain the rotational velocity by supplying force (torque) to the knurled section on the rotating base. Keep an eye on the indicator disk and make sure that it does not deviate from the confines of the indicator bracket. Once a constant rotational velocity has been attained, use a stopwatch to time ten revolutions. Make sure you count 10 complete revolutions. It is best to have one person maintain the velocity and another count and operate the stopwatch. Divide the time in ten and record the period.

9. To vary the centripetal force, replace the clamp-on-pulley on the track and hang a different mass over the pulley. Make sure that you do not re-adjust the radius. Record the new hanging mass and repeat the procedure and record the period for each variation. Repeat for a total of 5 different hanging masses.
Analysis and Results for Part II:

1. **The weight of the hanging mass is equal to the centripetal force applied to the brass object, in order to keep it going in a circle.** Make sure you understand WHY (using physical principles) the previous sentence is true! **Ask your instructor to confirm that your logic is correct.** Calculate the theoretical centripetal force by multiplying the hanging mass (+ weight hanger) by the gravitational acceleration constant, \( g \), and record this value.

2. Calculate the square of the period for each run and record. Using eqn (1) from above, calculate the experimental centripetal force applied to the brass object. Note: the \( M \) here is the mass of the brass object. The hanging mass has already been used to calculate your theoretical centripetal force. Record the experimental centripetal force for each hanging mass.

3. Calculate the percentage difference between the theoretical centripetal force and the experimental centripetal force for each hanging mass.

**Sample Data:**

<table>
<thead>
<tr>
<th>Hanging Mass + weight hanger, ( m ) (g)</th>
<th>Brass Object, ( M ) (g)</th>
<th>Radius ( r ) (m)</th>
<th>Period, ( T ) (s)</th>
<th>( T^2 ) (s²)</th>
<th>Theoretical Centripetal Force, ( mg ) (N)</th>
<th>Experimental Force (eqn 1) (N)</th>
<th>% Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.3</td>
<td>209.7</td>
<td>.21</td>
<td>2.308</td>
<td>5.327</td>
<td>.297</td>
<td>.326</td>
<td>8.9%</td>
</tr>
<tr>
<td>40.3</td>
<td>209.7</td>
<td>.21</td>
<td>2.023</td>
<td>4.093</td>
<td>.394</td>
<td>.425</td>
<td>7.3%</td>
</tr>
<tr>
<td>50.3</td>
<td>209.7</td>
<td>.21</td>
<td>1.848</td>
<td>3.415</td>
<td>.493</td>
<td>.509</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

**Part III: Vary Mass of Brass Object** (which will result in the period varying)

1. The **radius of rotation and the hanging mass will be held constant for this part** of the experiment. Weigh the brass object again and record its mass. Hang the brass object from the side post and connect the string (the string must be level) from the spring to the object, as before.

2. Attach the clamp-on-pulley to the end of the track nearest the side post. Attach a string (the string must be level) to the brass object and hang a known, measured mass over the clamp-on-pulley. Record this hanging mass and the mass of the weight hanger.

3. Select a radius by aligning the line on the side post with any position on the rule. While pressing down on the side post to assure that it is vertical, tighten the thumbscrew. Make sure that there is some tension in the spring and a bit of room for the spring bracket and the indicator bracket to move up and down. Record this radius.

4. The brass object on the side post must hang vertically, which means that the string must be aligned with the line on the side post (i.e. the string must be vertical). On the center post, adjust the spring bracket vertically until the string from which the object hangs on the side post is aligned with the line on the side post.

5. Align the indicator bracket on the center post with the orange indicator disk. This must be done BEFORE you remove the hanging mass from the system.
6. Remove the hanging mass and the clamp-on-pulley from the system. It is **okay** that the orange indicator disk will move away from the indicator bracket and some strings will no longer be perfectly vertical or horizontal.

7. Rotate the apparatus using the knurled section on the rotating base, increasing the speed until the indicator disk is aligned in the indicator bracket on the center post. This indicates that the string supporting the brass object is **vertical** and thus the hanging object is at the desired radius and should have the constant centripetal force equal to the hanging weight.

8. You must maintain the rotational velocity by supplying force (torque) to the knurled section on the rotating base. Keep an eye on the indicator disk and make sure that it does not deviate from the confines of the indicator bracket. Once a constant rotational velocity has been attained, use a stopwatch to time ten revolutions. Make sure you count 10 complete revolutions. It is best to have one person maintain the velocity and another count and operate the stopwatch. Divide the time in ten and record the period.

9. To vary the mass of the brass object, you can remove one or both of the side masses. Make sure that you do not readjust the radius or readjust the hanging mass. Record the new mass of the brass object and repeat the procedure and record the period for each variation. Repeat for all three configurations of the brass object (both side masses on, one side mass on, no side mass on).

### Analysis and Results for Part III:

1. **The weight of the hanging mass is equal to the centripetal force applied to the brass object, in order to keep it going in a circle.** Make sure you understand WHY (using physical principles) the previous sentence is true! **Ask your instructor to confirm that your logic is correct.** Calculate the theoretical centripetal force by multiplying the hanging mass (+ weight hanger) by the gravitational acceleration constant, \( g \), and record this value.

2. Calculate the square of the period for each radius and record. Using eqn (1) from above, calculate the experimental centripetal force applied to the brass object. Note: the \( M \) here is the mass of the brass object. The hanging mass has already been used to calculate your theoretical centripetal force. Record the experimental centripetal force for each configuration of the brass object.

3. Calculate the percentage difference between the theoretical centripetal force and the experimental centripetal force for each configuration of the brass object.

#### Sample Data:

<table>
<thead>
<tr>
<th>Hanging Mass + weight hanger, ( m ) (g)</th>
<th>Brass Object, ( M ) (g)</th>
<th>Radius ( R ) (m)</th>
<th>Period, ( T ) (s)</th>
<th>( T^2 ) (s²)</th>
<th>Theoretical Centripetal Force, ( mg ) (N)</th>
<th>Experimental Force (eqn 1) (N)</th>
<th>% Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.3</td>
<td>209.7</td>
<td>.21</td>
<td>1.851</td>
<td>3.426</td>
<td>.493</td>
<td>.507</td>
<td>2.8%</td>
</tr>
<tr>
<td>50.3</td>
<td>157.6</td>
<td>.21</td>
<td>1.606</td>
<td>2.579</td>
<td>.493</td>
<td>.507</td>
<td>2.8%</td>
</tr>
<tr>
<td>50.3</td>
<td>105.7</td>
<td>.21</td>
<td>1.320</td>
<td>1.742</td>
<td>.493</td>
<td>.503</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

5. **Questions** (answer in conclusion)
1. When the radius is increased, does the period of rotation increase or decrease?

2. When the radius and the mass of the rotating object are held constant, does increasing the period increase or decrease the centripetal force?

3. As the mass of the brass object is increased, does the centripetal force increase or decrease?