Centripetal Force

Objectives
After completing this lab, you should be able to:

- Define and identify centripetal forces
- Explain the relationship between the radius of rotation and the period of rotation
- Explain the relationship between the centripetal force and the rotational period
- Explain the relationship between the mass of a rotating object and its period

Equipment
- Centripetal Force Apparatus
- Stopwatch
- Bubble level

Introduction
The centripetal force acting on an object of mass $M$ moving with speed $v$ in a circle of radius $r$ is:

$$F = \frac{Mv^2}{r}$$

You should convince yourself that the units match on both sides of each equal sign. Given that the speed, $v$, can be written as $v = \frac{2\pi r}{T}$ where $T$ is the period of revolution, this can be rewritten as

$$F = \frac{4\pi^2 Mr}{T^2}$$

The purpose of the first three parts of the experiment is to show that centripetal force exerted by a spring at a given rotational velocity is correctly given by the equation above. We can accomplish this by varying one of the variables $F, M,$ or $r$ while the other two are constants. Our method will consist of measuring the period of rotation and plot this (or rather its square or inverse square) against the variable of interest, $F, M,$ or $r$. We will then compare the slope of these plots to the expected slope from the equation above.

Procedure
Start by leveling the Apparatus. It is important that the rotational platform be level or the mass and spring will oscillate as the platform rotates. To level the base, do the following:
a. Attach or move the 300-gram counter mass to either end of the aluminum track. Tighten the screw so the mass will not slide. Remove the brass mass if present.

b. Rotate the track so that it is parallel to one side of the “A-base” and adjust the leveling screws until the track is level as measured using a bubble level sitting on the track.

c. Rotate the track again so that it is parallel to the other side of the “A-base” and adjust the leveling screws until it is level.

Figure 1. The centripetal force apparatus

General Procedure Steps

Use the procedure steps A-H below for the first three parts of the experiment. Some steps may not be necessary, i.e., if the mass $M$ is to be held constant, then Step A should be ignored after the first trial of that experiment.

A. Adjust the mass $M$ (if necessary) by adding or removing brass disks. Measure the mass using a centigram balance.

B. Set the radius of rotation (if necessary) by sliding the side post along the aluminum track. Measure the radius from the center post to the groove using the centimeter scale on the track.

C. Attach the calibration weight $mg$. This will vary depending on the experiment.
D. Raise or lower the spring support until the string holding the round brass mass from the slide post is hanging vertically. Ask your instructor to explain if this is unclear.

E. Position the marker at the same height as the pink plastic disk. This marks how far the spring stretches due to the force of the calibration weight.

F. Remove the calibration weight.

G. Rotate the platform by hand. Adjust the rotational speed until the marker and pink disk are at the same height. Now the force exerted by the spring (now also the centripetal force) is the same as the force needed to suspend the calibration weight. That is, now \( F = W = mg \).

H. Manually maintain the speed of the platform. Ask your partner to measure the time that it takes the platform to complete 20 revolutions using either a hand stopwatch or the stopwatch program on the computer. It helps to start counting at zero so that you don’t count 19 revolutions by mistake.

**PART 1: Varying Radius (constant force and mass)**

For this part of the experiment, the centripetal force \( F \), which is also the calibration weight \( mg \), and the mass \( M \) will be constant.

1. Measure the mass of \( M \). Choose a calibration mass \( m \) (30 to 50 g will be fine).
2. Select an initial radius by adjusting the distance between the side post and center post.
3. Perform the experiment by following the General Procedure Steps above, being sure to adjust the pink ring each time.
4. Select four other radii and repeat the experiment for each.

**Table 1:** (Make a table like this in your notebook.)

<table>
<thead>
<tr>
<th>Trial</th>
<th>Radius (m)</th>
<th>20T (s)</th>
<th>( T^2 ) (s^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
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<td>4</td>
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</tr>
<tr>
<td>5</td>
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<td></td>
</tr>
</tbody>
</table>

1. Calculate the calibration force (this is also the centripetal force).
2. Calculate the square of the period \( (T^2) \) for each trial.
3. Plot the radius versus the square of the period.

4. Draw what you think is the best-fit line through the data points and determine the slope of the line.

5. Determine the centripetal force from the slope.

6. Compare the centripetal force determined from the slope with the centripetal force that must be the calibration weight (a fractional difference with comment will suffice).

   **Table 2:** (Make a table like this in your notebook.)

<table>
<thead>
<tr>
<th>Centripetal force $F$ from $mg$</th>
<th>Centripetal force $F$ from slope</th>
<th>Fractional difference (%)</th>
</tr>
</thead>
</table>

**PART 2: Varying Force (constant radius and mass $M$)**

For this part of the experiment, the radius of rotation and $M$ will be constant. Construct two new tables in your notebook that are similar to Tables 1 and 2.

1. Measure the mass of $M$. Choose a radius. These two quantities will be constant.

2. Select an initial calibration weight.

3. Perform the experiment by following the General Procedure given earlier.

4. Select four other calibration weights and repeat the experiment for each.

   **Table 3:** (Make a table like this in your notebook.)

<table>
<thead>
<tr>
<th>Mass $M$:</th>
<th>Radius $r$:</th>
<th>Slope from graph:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Calibration mass $m$ (kg)</th>
<th>Centripetal force $mg$ (N)</th>
<th>$20T$ (s)</th>
<th>$1/T^2$ (s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td>5</td>
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</tbody>
</table>

5. Calculate the centripetal force for each calibration mass.

6. Calculate the inverse square of the period ($1/T^2$) for each trial.
7. Plot the centripetal force versus the inverse square of the period.

8. Draw what you think is the best-fit line through the data points and determine the slope of the line.

9. Determine the mass \( M \) from the slope.

10. Compare the mass \( M \) that you measured with \( M \) that you calculated from the slope.

\[ \text{Table 4: (Make a table like this in your notebook.)} \]

<table>
<thead>
<tr>
<th>Mass ( M ) measured</th>
<th>Mass ( M ) from slope</th>
<th>Fractional difference (%)</th>
</tr>
</thead>
</table>

\[ \text{PART 3: Varying Mass (constant radius and force)} \]

For this part of the experiment, the radius of rotation and centripetal force (calibration weight) will be constant. Construct two new tables in your notebook that are similar to Tables 1 and 2.

1. Choose a radius and calibration weight. These two quantities will be constant.

2. Select an initial mass \( M \). Measure this using a centigram balance.

3. Perform the experiment by following the General Procedure given earlier.

4. Select four other masses and repeat the experiment for each.

\[ \text{Table 5: (Make a table like this in your notebook.)} \]

<table>
<thead>
<tr>
<th>Calibration mass ( m ):</th>
<th>Calibration weight ( mg ):</th>
<th>Radius ( r ):</th>
<th>Slope from graph:</th>
</tr>
</thead>
</table>

\[ \begin{array}{|c|c|c|}
\hline
\text{Trial} & \text{Mass } M \text{ (kg)} & 20T \text{ (s)} & T^2 \text{ (s}^2) \\
\hline
1 & & & \\
2 & & & \\
3 & & & \\
4 & & & \\
5 & & & \\
\hline
\end{array} \]

5. Calculate the square of the period \( (T^2) \) for each trial.

6. Plot \( M \) versus the square of the period.

7. Draw what you think is the best-fit line through the data points and determine the slope of the line.
8. Determine the radius \( r \) from the slope.

9. Compare the radius \( r \) that you measured with \( r \) that you calculated from the slope.

10. Compare the two radii in the table below.

   **Table 6:** (Make a table like this in your notebook.)

<table>
<thead>
<tr>
<th>Calculated ( r )</th>
<th>( r ) from the slope</th>
<th>Fractional difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
</tr>
</tbody>
</table>