PHY 111L Activity 5

Uniform Circular Motion: Centripetal and Centrifugal Forces

Name: _____ ID #:_____

Section: _____ Date: _____

Lab Partners: _____ TA initials: _____

Objectives

1. Introduce Centripetal and Centrifugal forces, as well as uniform circular motion
2. Experimentally verify the forces involved in uniform circular motion (lab report)
3. Investigate how an object's uniform circular motion is affected by its mass and radius of travel

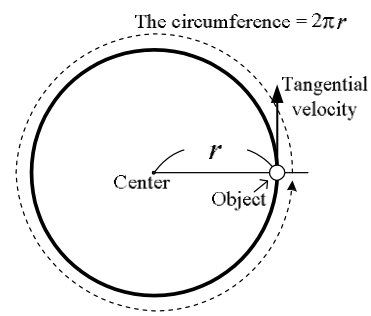
Materials & Resources

1. Computer with DataStudio and photo gate
2. Uniform Circular Motion apparatus with slot and hanging mass sets

Introduction

This lab illustrates the concept of uniform circular motion, which is different from uniform linear motion because the direction is constantly changing, even though the speed remains constant. This constant change in direction is caused by acceleration towards the center of the circular motion. The force responsible for this is known as a centripetal force, which can be represented as:

$$F_c = (mv^2) \div r$$



where m is the mass of the object, v is the tangential velocity, and r is the radius of the motion, as shown in the figure to the right. The above expression reveals that the centripetal force required to confine an object to uniform circular motion is proportional to the velocity of the object squared, yet inversely proportional to the radius of the object's motion. That is, the faster the object is moving or the closer the object is to the center of its circular motion, the stronger the force must be to maintain the constant change in direction needed for uniform circular motion. Now, if the circular motion is really uniform, then the period of revolution, the time needed for the object to complete a cycle, is given by:

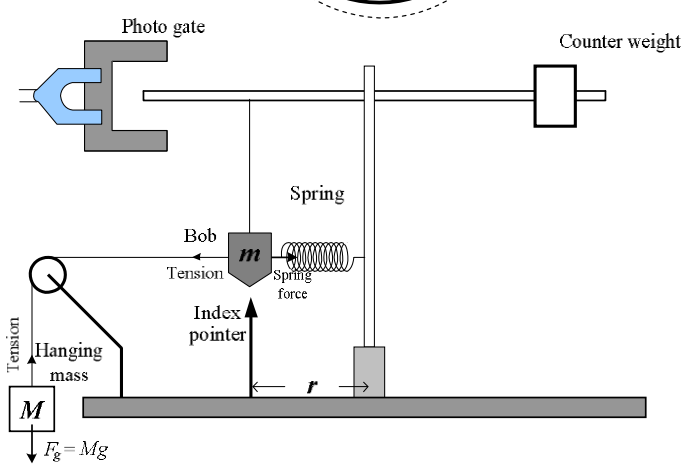
$$T = (2\pi r) \div v$$

In this experiment, the radius of motion (indicated by the index pointer) is measured with a ruler and the period is measured using a photo gate. Then the tangential velocity is calculated as follows:

$$v = (2\pi r) \div T$$

The centripetal force in this experiment is created by the spring, as shown to the right, and is thus given by:

$$F_c = (4\pi^2 mr) \div T^2$$

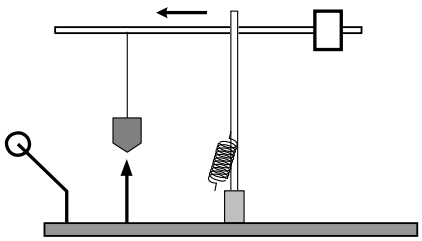


The force created by a spring is proportional to how far past equilibrium it is stretched, in this case represented by r as shown. The farther the spring is stretched the more force it produces in the opposite direction. To find the force from the spring for a particular r, use the gravitational force, $F_g = Mg$, when the system is not spinning as shown above to balance the force from the spring. Since this is the force needed to stretch the spring to radius r, it can be inferred that this is the centripetal force that the spring applies to m during the uniform circular motion.

1. *Uniform Circular Motion with Fixed Radius, Different Masses (Lab report)*

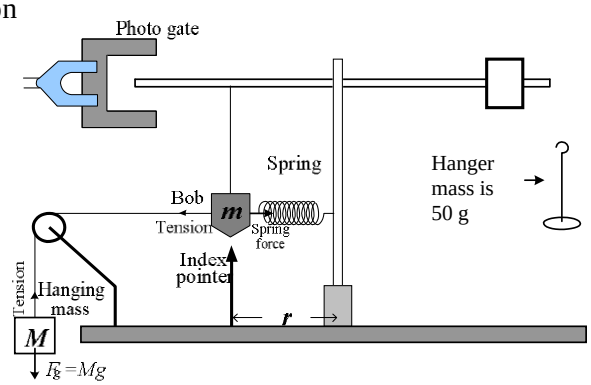
Procedure:

1) Setup the circular motion apparatus as shown in Figure 1, set the index pointer to r_1 = 18 cm, place the still bob *precisely* over the index pointer by sliding the top bar as shown, then tighten the top bar in that position. Use the meter stick to measure r_1, then disconnect the bob from the apparatus and use a balance to measure the mass m of the bob only; record your results below with correct significant figures, uncertainty, and units.



r_1 = _____ ± _____ ( ); m = _____ ± _____ ( )

2) Reconnect the bob to the apparatus, attach the spring, and position the apparatus so that the end of the top bar can move freely through the photo gate, triggering it without making physical contact, and then connect the hanging mass to the bob with the pulley and string. Carefully add mass to the hanger until the bob is again positioned over the index pointer as shown in Figure 2. Be sure the bob and the hanger are both still when this happens!



3) Disconnect the string from the bob, measure the combined mass M_1 of the hanger, added masses, and string with the balance, and then calculate the force F_{g1} that the hanging mass applies to the bob. Correctly record the results for M_1 and F_{g1}.

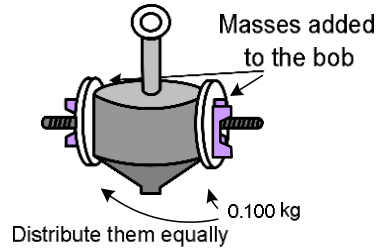
M_1 = _____ ± _____ ( ); F_{g1} = _____ ± _____ ( ), where g = 9.807 $^{m}/s^2$ and $\Delta F_{g1} = \Delta M_1 * g$.

4) Connect your photo gate to the Pasco interface, create an experiment in DataStudio, and select a photo gate for 2 of the digital channels, even though you will only be using 1 photo gate in this experiment. Display a table with "Time Between Any Gates" as the data source; the period T of the motion will display in the right column.

5) Practice spinning the apparatus using the grip on the top of the rotation pole until the bottom tip of the bob lines up with the index pointer *consistently* for each revolution, thus maintaining uniform circular motion for the bob. Once you have mastered this, click Start and let DataStudio record the period of several (at least 15) cycles of uniform circular motion before clicking Stop and letting the apparatus naturally come to rest. Select "mean" from the table's "Σ" drop-down and record your average value for period T in the first row of the table below. Then calculate the tangential velocity v and the centripetal force F_{c1} and record those values in the table as well.

Rotating bob mass, m	Average period, T	Tangential speed, $v = {}^{2\pi r}/_{T}$	Centripetal force, $F_{c1} = mv^2/r$

6) Add a 50 g mass to each side of the bob as shown in Figure 3 and fill in the second row of the table by repeating step 5 with the more massive bob. Replace the 50 g mass on each side of the bob with a 100 g mass on each side, then repeat step 5 for the third row. Add the two 50 g masses back to each side of the bob for a total of 300 added grams, and then repeat step 5 again to fill in the fourth row of the table.



7) Enter your calculated values for F_{c1} into a "New Empty Data Table;" find and record the mean and standard deviation below.

F_{c1} = _____ ± _____ ( )

8) Calculate the percent difference between $\boldsymbol{F_{g1}}$ and $\boldsymbol{F_{c1}}$ and record below. Show your work.

$$\% \text{ difference} = \frac{|F_{g1} - F_{c1}|}{\frac{1}{2}(F_{g1} + F_{c1})} \times 100 = _____ = _____ \%$$

9) Calculate, and record below, the absolute value of the difference between $\boldsymbol{F_{g1}}$ and $\boldsymbol{F_{c1}}$, and the sum of $\Delta\boldsymbol{F_{g1}}$ and $\Delta\boldsymbol{F_{c1}}$.

Questions: $|\boldsymbol{F_{g1}} - \boldsymbol{F_{c1}}| =$ _____ ( ) $\Delta\boldsymbol{F_{g1}} + \Delta\boldsymbol{F_{c1}} =$ _____ ( )

1) Briefly explain why $\boldsymbol{F_{g1}}$ should be equal to $\boldsymbol{F_{c1}}$ above, irrespective of what the mass of the bob is.

2) Does your experimental data support this claim? Justify your answer below.

3) Would your results for $\boldsymbol{F_{g1}}$ be higher or lower (circle one) if the hanging mass were not precisely still? Justify your answer below.

4) Given the way the apparatus works, it is likely that the bob traveled on a slightly elliptical path. Based on your results, did the bob pass the pointer on the long or short (circle one) axis of the ellipse? Why?

5) Briefly explain what your value for $|\boldsymbol{F_{g1}} - \boldsymbol{F_{c1}}|$ represents in this experiment below.

6) Briefly explain what your value for $\Delta\boldsymbol{F_{g1}} + \Delta\boldsymbol{F_{c1}}$ represents in this experiment below.

7) Which of these calculated values is greater, $|\boldsymbol{F_{g1}} - \boldsymbol{F_{c1}}|$ or $\Delta\boldsymbol{F_{g1}} + \Delta\boldsymbol{F_{c1}}$? (circle one) What does this comparison tell you about the *validity* of your experimental results? Justify our answer below.

8) Which of your experimental values above is higher, $\boldsymbol{F_{g1}}$ or $\boldsymbol{F_{c1}}$? (circle one) Based on the measurements and the equations for $\boldsymbol{F_{g1}}$ and $\boldsymbol{F_{c1}}$, list <u>all</u> error sources that are *physically consistent* with this result.

9) Evaluate which of these errors most likely accounts for this discrepancy in your experimental results. Justify your answer below.

2. *Uniform Circular Motion with Other (Larger) Radii*

Procedure:

1) Repeat steps 1 – 3 above, but increase the radius by about 2 cm. Enter your measured values for r_2 and M_2, and your calculated value for F_{g2}, with correct significant figures, uncertainty and units below.

r_2 = _____ ± _____ ( ); M_2 = _____ ± _____ ( ); F_{g2} = _____ ± _____ ( )

2) Repeat steps 5 – 6 above in order to fill in the table below.

Rotating bob mass, m	Average period, T	Tangential speed, $v = {}^{2\pi r}/_{T}$	Centripetal force, $F_{c2} = mv^2/r$

3) Repeat step 7 above and correctly record your results for F_{c2} here:

F_{c2} = _____ ± _____ ( )

4) Repeat steps 1 – 3 above, but increase the radius by another 2 cm. Enter your measured values for r_3 and M_3, and your calculated value for F_{g3}, with correct significant figures, uncertainty and units below.

r_3 = _____ ± _____ ( ); M_3 = _____ ± _____ ( ); F_{g3} = _____ ± _____ ( )

5) Repeat steps 5 – 6 again in order to fill in the table below.

Rotating bob mass, m	Average period, T	Tangential speed, $v = {}^{2\pi r}/_{T}$	Centripetal force, $F_{c3} = mv^2/r$

6) Repeat step 7 above and correctly record your results for F_{c3} here:

F_{c3} = _____ ± _____ ( )

Questions:

1) How does increasing the radius of rotation affect the centripetal force on the bob?

2) How does increasing the radius of rotation affect the period of the bob's motion?

3) How does increasing the radius of rotation affect the velocity of the bob?

4) How does increasing the mass of the bob affect the velocity of the bob?