IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 12, Issue 6 Ser. III (Nov. – Dec. 2020), PP 27-34
www.Iosrjournals.Org

Centripetal Force Lab Report

El-Zayat

Date of Submission: 01-12-2020 Date of Acceptance: 15-12-2020

I. Research Question:

How does the radius of a mass moving in a circular affect the frequency it spins with in a horizontal circular motion?

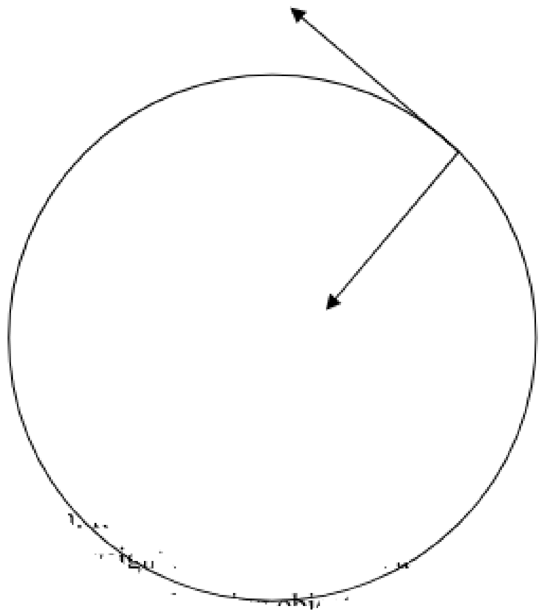
II. Background:

An object moving in a circular path will always have a linear velocity and acceleration. One might say that acceleration is a vector and therefore needs a certain direction. A circular path is always changing direction due to the direction of its acceleration. When an object is moving in a circular path the acceleration is directed towards the center of the circle and the sum of all forces is the centripetal force.

$$a_{cp}=\frac{v^2}{r}$$

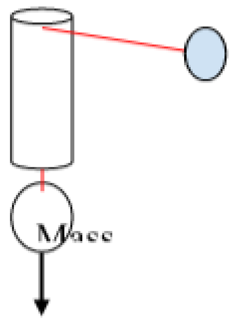
When moving in a circle the distance traveled is equal to the circumference of the circle which is $2\pi r$. Since velocity is equal to distance over time then the velocity of something moving in a circular path is $\frac{2\pi r}{t}$. The velocity it moves with is always tangential to the circular path. In figure 1 the direction of the acceleration and velocity of an object moving in a circular path are indicated.

Figure 1: Velocity & Acceleration Vectors



In the case of this lab there is a rubber stopper rotating in a circular path. It is affected by two forces assuming air resistance is negligible. It is pulled downwards by its own weight and string applies a tension force on it. The Tension in the string is equivalent to the weight of the hanging object.

Figure 2: Force Annotations



$$T = W = Mg$$

Vertically, the rubber stopper is in equilibrium. Hence, the tension in the string has a vertical component balancing the weight of the mass. Although the rubber stupper is not completely in equilibrium, there is a net force acting on it that causes it to change direction, meaning it accelerates towards the center - changing direction and not speed.
According to Newtons second Law:

$$F_{net} = ma$$

It has previously been established that $a_{cp}=\frac{v^2}{r}$, therefore

$$F_{net} = m\frac{v^2}{r}$$

Assuming that the string is perfectly horizontal, although in reality it is not, one can say that the tension in the string is the net force acting on the rubber stopper. Since it is already known that T = W and W = Mg, one will find that

$$Mg = \frac{mv^2}{R}$$

Where M is the mass attached to the other end of the string, m is the mass of the rubber stopper, v is the linear speed of the rubber stopper and r is the radius of the circular path of the rubber stopper. We have previously established that $v=\frac{2\pi r}{t}$ by substituting this in for v the new equation is: 1

$$Mg = \frac{4\pi^2 mR}{T^2}$$

Through Rearranging it one can finally get:

$$T^2 = \frac{4\pi^2 m}{Mg} \times R$$

It is evident here that R is a coefficient of, $\frac{4\pi^2 m}{Mg}$, all being constants. The linearization of this equation makes it possible to graph the data and visually show the relationship between T^2 and R.

III. Procedure

A. Variable Selection

1. Independent Variable: The radius of the circle is the independent variable for this lab. In this given procedure a wide range of radii were used, ranging from approximately .19 to .7 meters. The range is important as it needs to have a difference large enough where there will be notable differences in the data, as if the radii are close together it will serve as an unreliable independent variable, with data points very similar to one another. To ensure accuracy, the meterstick listed in the materials will be used to precisely measure the length of the string. Subsequent to the beginning of each trial the meter stick will be positioned at the top of the tube and measured as accurately as the naked eye possibly can. However, an assumption made here is that the angle will remain at the horizontal throughout.

2. Dependent Variable: The time taken to complete ten revolutions for each given radius is the dependent variable. A timer will be set at the beginning of the trial and will be stopped at the instant ten the swinger reaches the end point. However, the results will be as accurate as the human eye can be. The time will be taken five times for seven total radii. An assumption made here is that the swinging mass will be moving at constant speed.

3. Controlled Variables:

a) **Swinging Mass:** For each trial the swinging mass remains constant. In order to keep the data consistent and accurate this must be the case.

b) **Hanging Mass:** For each trial the hanging mass must remain the same. This is because a component of the hanging mass is the sum of all forces, thus is the centripetal force. By changing the mass the relationship between T^2 and r cannot be independently explored as the conditions will not remain the same.

c) **Angle the Mass Swings at:** The variable at hand cannot completely be controlled, however, the effect of it can certainly be reduced. The angle that the mass is swinging at is assumed to be horizontal. However, due to certain components of gravity, this is simply impossible. The mass will move at an angle lower than the horizontal and in order to reduce the angle it moves at, there will be an attentive observer who will supervise it to make sure it is as close to the horizontal as possible for the majority of the lab. Unfortunately having this will certainly deviate the data far from what it is meant to be.

Hypothesis:

If the orbital radius is increased than the square of the period will increase proportionally, due to their direct linear relationship.

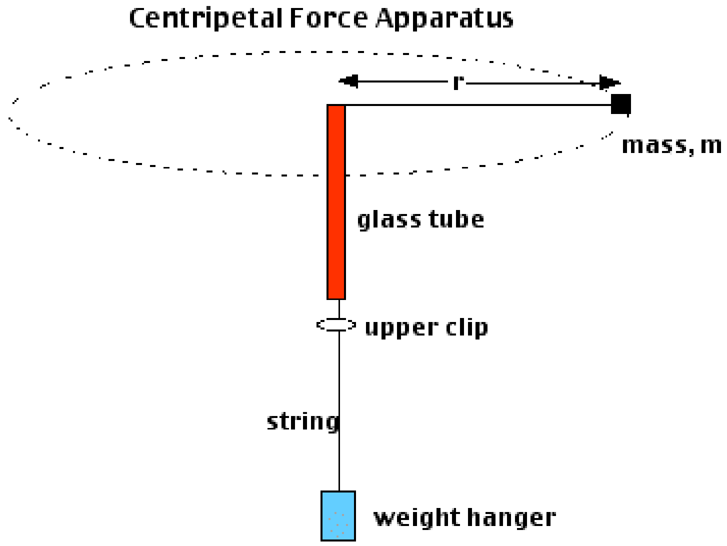
Materials:

- Swinging Mass (12g may vary)
- Large Mass (94g may vary)
- String
- Large tube with rounded ends
- Colored tape
- Timer
- Helmet/protective eyewear
- Meter stick
- Data sheet

Steps:

1. Put the long string through the large tube. Once it's settled in a good position tape the string to the inside of the tube.
   a. Be sure that the tape is strong enough to hold the string in place.
   b. Be sure that the tape is settled so that the radius matches the planned one.
2. Tie the swinging mass onto the end of the string coming out of the smoothened side of the tube.
3. Attach the large mass onto the opposite end of the tube.
   a. This mass will hang in place for the entirety of the procedure.
4. Pick the tube up vertically.
   a. The large mass should be on the bottom of the tube.
5. Practice whirling the spinning mass so that the mass is spinning at a very small angle below the horizontal.
   a. During this test run make sure to check that the tape is holding the string in place. If the tape even moves a bit the radius will not be consistent during the trial and a source of error would be created.
6. Once you feel like you have practiced enough whirl get your stopwatch ready to measure the time taken for ten full revolutions.
7. Begin whirling and record your data for ten revolutions.
8. Repeat Steps 5-7 four more times with the same radius and record the data for each trial.
9. Repeat steps 5-8 for six more different radii.

Figure 3: Diagram of setup



Citation in works cited

Safety Warnings:
Fortunately, this lab has a very low risk of harming anyone conducting this procedure. Regardless, masses are being used thus, it is important that the conductor not wear any open toes shoes in the case that the string tears. Furthermore, any headgear to guard the eyes is important as the spinning mass may hit the eye.

IV. Data Collection

Raw Data:

Table 1A below shows the data collected from the stopwatch. The first column shows the radii selected as well as it's uncertainty. The second through sixth columns all show the time taken for the ball to complete ten periods around the disc. Seven different radii were used, and each tried five times in an attempt to minimize random errors. However, fortunately all data collected seemed to be within a consistent and accurate range of one another.

Table 1A: Measured Times

	Trial 1 Radius	Trial 2	Trial 3	Trial 4	Trial 5
+/- 0.003 m	All data in seconds				
0.42	4.97	5.06	5.06	4.87	4.67
0.38	5.51	5.60	5.49	4.94	4.93
0.57	6.13	5.90	5.81	5.62	6.06
0.19	3.73	3.85	3.79	3.99	3.67
0.63	5.17	5.41	4.76	5.47	5.11
0.22	3.90	3.86	3.64	3.84	4.00
0.70	5.62	5.33	5.62	5.96	5.79

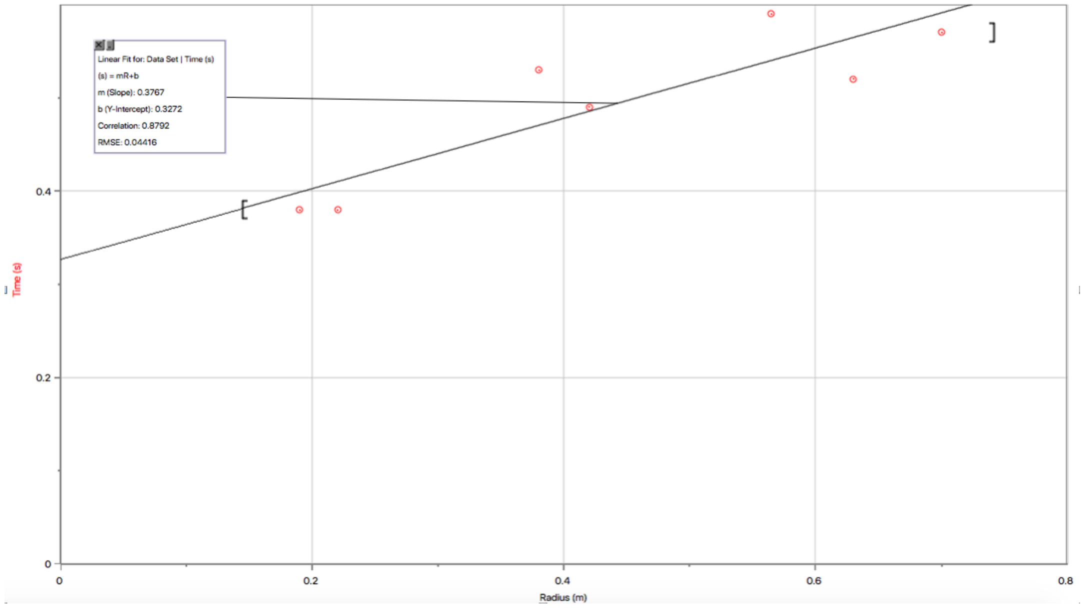
Processed Data

In Table 2A, the radii are again depicted, although, this time, averages for the five trials have been calculated, with uncertainties calculated for each. To calculate the averages, the data from all five trials was added together and divided by five. As observed in the tables, with an increase in radius, there is going to be an evident change in the time taken to complete ten periods around the disk as the distance traveled will increase. Surprisingly, this was not completely consistent for all of the trials. Hence, there was a random error that took place in the data. Regardless, subsequent to the calculation of the averages, the absolute uncertainties were calculated.

Table 2A:

Radius(m)	Time			Period		
+/- 0.003 m	avg (sec)	Unc	%Unc	Sec	Unc	%Unc
0.420	4.93	0.2	3.96%	0.49	0.02	3.96%
0.380	5.29	0.3	6.33%	0.53	0.03	6.33%
0.565	5.90	0.3	4.32%	0.59	0.03	4.32%
0.190	3.81	0.2	4.20%	0.38	0.02	4.20%
0.630	5.18	0.4	6.85%	0.52	0.04	6.85%
0.220	3.85	0.2	4.68%	0.38	0.02	4.68%
0.700	5.66	0.3	5.56%	0.57	0.03	5.56%

Figure 4: Radius and time graph



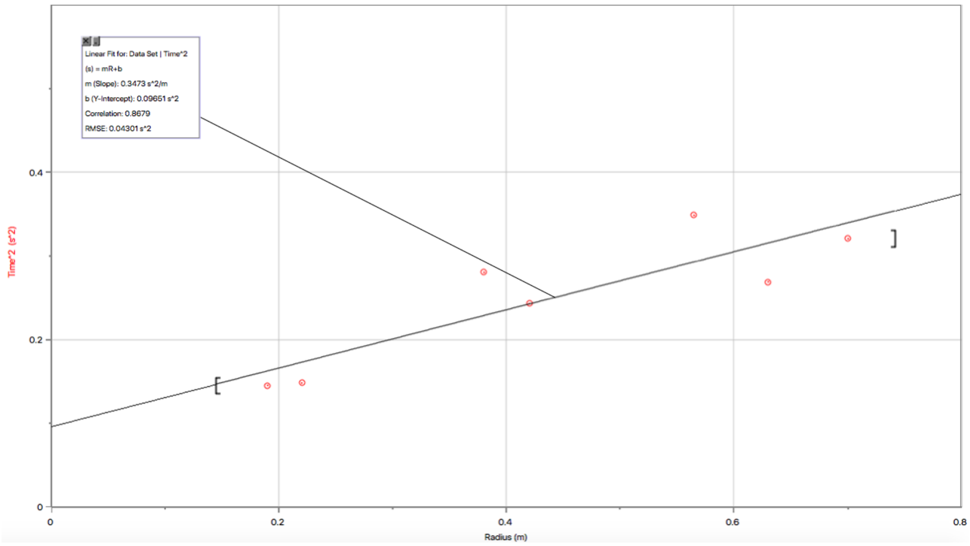
The graph above represents the relation between the time and the radius, while it appears to be proportional, theoretically, the radius should be in proportion to the T^2 value and not be proportional to the regular time taken. To confirm this theory the data will be further processed to square the time values.

Table 2B:

T^2 sec^2	%Unc	Period^2 Unc	Unc(Absolute)
Avg	T^2		Sec^2
0.24	7.92%	0.02	0.02
0.28	12.7%	0.04	0.04
0.35	8.64%	0.03	0.03
0.14	8.41%	0.01	0.01
0.27	13.7%	0.04	0.04
0.15	9.36%	0.01	0.01
0.32	11.1%	0.04	0.04

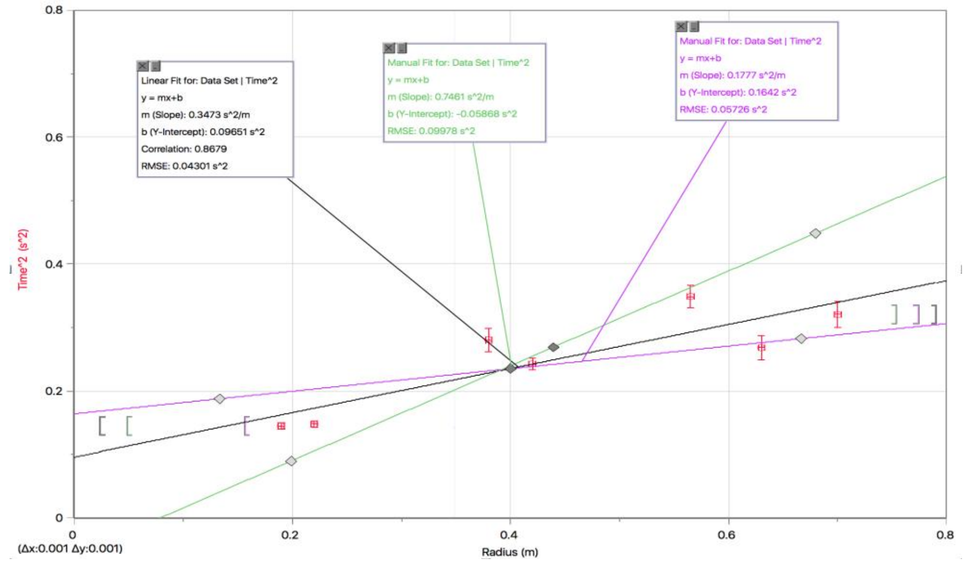
In table 2B processing was continued to obtain the T^2 values and to find the absolute uncertainties. To find the absolute uncertainty, the percent uncertainty must be found. This can be done by doubling the period percent uncertainty in table 2A. After the percent uncertainty is found the absolute uncertainty is found by multiplying the T^2 value by the percent uncertainty for each given radius.

Figure 5: Line of Best Fit



The slope of the line is 0.345 and the y-intercept is .096. Unfortunately, the line of best fit does not pass through all the lines, failing to indicate the linear relationship between the two. A correlation coefficient value of .86 further verifies the sources of error that will later be stressed upon. In addition, the slope's uncertainty will be calculated through the use of maximum and minimums indicated by error bars.

Figure 6: Line of best fit with the max & min slopes



Max slope - Best fit slope = .7461 - .3473 = .3988

Best fit slope - Min slope = .3473 - .1777 = .1696

Slope with uncertainty = .3473$\pm$.3988

Percent uncertainty = .3988/.3473 * 100 = 114.8%

As shown in figure 6, the max and min slopes were calculated to be .7461 and .1777 respectively. In figure 4 the slope obtained was .3473 T^2/m. On the other hand, in figure 5 above, the maximum and minimum slopes were obtained and illustrated the uncertainties. Through the subtraction of the best fit slope from the max slope, the value obtained is seen to be .3988. As the minimum slope is subtracted from the best fit, the value obtained is .1696. Hence, the more accurate representation of the slope for the function is 3473$\pm$.3988. Furthermore, the calculation of the percent uncertainty found it to be greater than 100%. This means that the data measured is small in quantity, however, has a very wide distribution which is apparent when looking at the graph.

Linearization

The equation established in the beginning was $T^2 = \frac{4\pi^2 m}{Mg} \times R$ from this equation it is evident that it matches the linear $Y = mx + b$ equation with $\frac{4\pi^2 m}{Mg}$as the slope and the y intercept being at the origin. The masses listed in the materials appear to be 18 and 88 grams and a gravitational field strength of 9.81 N/Kg Upon plugging the numbers in this equation the slope can be calculated. $\sqrt{\frac{4\pi^2 .012}{.94(9.81)}}$. The theoretical slope for these given masses is 0.9073. The best fit slope was calculated to be .3473, from this information the percent error between the two can be calculated. Percent error =

$$\left|\frac{Theoretical - Experimental}{Theoretical}\right| * 100 = \left|\frac{.6072 - .3473}{.6072}\right| * 100 = 43.07\%$$

A 43% percent error is a very high value and will thus will further validate the sources of error in this lab.

V. Conclusion and Evaluation:

Figure two shows the the period squared with the radius. While the line of best fit is linear the points plotted on the graph do not show the relation between the two. Through rearranging the equations introduced in the background information it is evident that the period squared should in fact be proportional to the radius. The trend in the data can barely be identified with a correlation coefficient of .86, it suggests a correlation between the two. Unfortunately, this was not accurately portrayed in the results, hence, it can be concluded that there were sources of error further limiting the potential of the lab. Through taking a look at figure 5 one can tell that there are both random and systematic errors. Systematic error is apparent as the graph does not go through the origin and random errors are apparent since the points are scattered under and above the line. While there can be many sources of error three of them can be listed as: inaccurate timing of one lap, friction due to air resistance, and variations in the speed and radius of the ball.

The conductors of this lab are all human, thus, it is expected that the results cannot possibly be timed perfectly by using just the naked human eye. One way to minimize the random error associated with the time measurements due to the human error, is to use a video camera to record a video for the orbiting object then playing it back in slow motion to measure the periodic time. With the help of a high frame rate camera, one revolution would correspond to a certain number of frames recorded by the camera until the rotating object reaches it starting position along the circular path. By counting the number of frames and knowing the number of frames per second of the recorded video, one can calculate the time corresponding to one revolution.

One of the major sources of error of the lab was the air resistance that the swinging mass faces during its path. In the beginning of the procedure it was assumed that there was no air resistance, however, in reality there was. The air resistance represents a systematic error since it will only work to increase the time taken to complete ten revolutions. Furthermore, the force caused by the air resistance would be constantly changing and thus affects each spin differently than the other. The only way to minimize the negative effect of the air resistance is to perform this procedure in a vacuum chamber and suck out all of the air. While this is a very costly method to minimize the effects of air resistance, it certainly is the most efficient.

Lastly, another source of error for this lab was the variations in the speed and radius of the ball during different stages of its path. While this lab was meant to be at the horizontal throughout the entirety of the lab, this is simply impossible. Since there will inevitably be an angle that the mass will be spun at the given radius is not accurate. Furthermore, the angle the ball is at will not be consistent either meaning that the radius will not be consistent throughout each trial either. In addition, due to air resistance the speed will not be consistent throughout and will be very unpredictable. These two sources of error can be solved in the future with one solution. A controlled motor can function to move the mass at a constant speed and remain at a constant radius throughout all trials.

To further enhance the understanding to the original topic a valuable extension is in need. While this lab succeeds at providing a good understanding of centripetal force it fails to address important parts of the topic. A valuable extension could be to do this lab again, however, rather than changing the radii one could change the mass of the swinging mass. While two masses are used in this lab, their effects are not tremendously discussed as they are both controlled. Hence, through changing one of the masses it could be interesting to see what that will result in. Furthermore, another extension that could be discussed is finding the relationship of the velocity to the angle. In the third source of error, it was introduced that that with changing velocities the angle would also change. Therefore, it would be interesting to have velocity as the independent variable and see how the angle changes accordingly.

Works Cited

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