Circular Motion Lab

Relationship between the centripetal acceleration and the angular velocity for an object in circular motion

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Abstract

Centripetal acceleration is the force that we feel when an object is undergoing an uniform circular motion such as when going around a curve, or on a loop to loop roller coaster. It is the force that keeps an object in a circular motion. Without it, Earth would move in a straight line and satellites would fall out of the sky. The lab that we have conducted is to verify the relationship that exists between the centripetal acceleration and the velocity of the object undergoing this force.

Introduction

Hypothesis

The relationship that exists between the centripetal acceleration and the angular velocity of the object is a square root function. As the centripetal acceleration increase (or gets more powerful), the velocity of the object also increases in proportion to the square-root of the radius multiplied by gravity. This is shown in the theory section of this lab report.

Theory

Variables

Within this lab, we experience a number of variables that we can and cannot control. The controlled variables in this lab are the mass (stopper) that is experiencing the centripetal acceleration and the radius of spinning motion.   Other variables such as the time it takes to complete one revolution can vary depending on a variety of reasons. The mass of the hanging weight is an independent variable, which varies depending on the number of washers that we tie to the end of the string. In order to eliminate components of the tension force, we are assuming that the stopper is rotating perpendicular to the plastic straw please refer to figure 1 for further explanation.

Equations

$$F_{centripital} = F_{net} = \frac{mv^2}{R}$$ Uniform Circular motion equation.

$$v = \frac{2\pi r}{t}$$ Velocity of object in circular motion

$$F_c = F_t$$

Forces Acting on Stopper

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

Forces Acting on Weight

$$\sum F_{net} = F_{tension} - F_{gravity} = 0$$

$$\therefore F_{tension} = F_{gravity}$$

Substituting the equations.

$$\sum F_{net} = F_{tension} = m\frac{\left(\frac{2\pi r}{t}\right)^2}{r}$$

Solve for t:

$$\Delta t = 2\pi\sqrt{\frac{mr}{F_g}}$$ The final equation to find the time it takes to rotate once

$$f = \frac{1}{\Delta t}$$

$$f = \frac{1}{2\pi\sqrt{\frac{mr}{F_g}}}$$

$$\therefore f = \frac{1}{2\pi}\sqrt{\frac{F_g}{mr}}$$

Linearizing the equation

$log\Delta f = \frac{1}{2}logMg - log\,2\pi\sqrt{mr}$ From this equation we can conclude that the variable that we are changing which is the Mg, the final graph will have an approximate slope of 0.5. The other two variables such as mass of the stopper and radius will be affected by a negative slope when compared to frequency.

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Experiment

Apparatus

- 1 plastic pipe .12m long x .01m diameter
- 1 meter long string
- 10 + metal washers
- 1 rubber stopper
- Chronographs
- Tape

Centripetial Acceleation Lab

Measuring centripetial acceleration through the use of tension force.

Y* The vertical component of the tension force is holding up the stopper.
X* The horizizontal component of the tension force is giving the centripital acceleration.

The stopper is spinning at an angle because there is gravity pulling it down. It is impossible to spin the stopper until it is exactly perpendicular to the plastic tube on the surface of the earth.
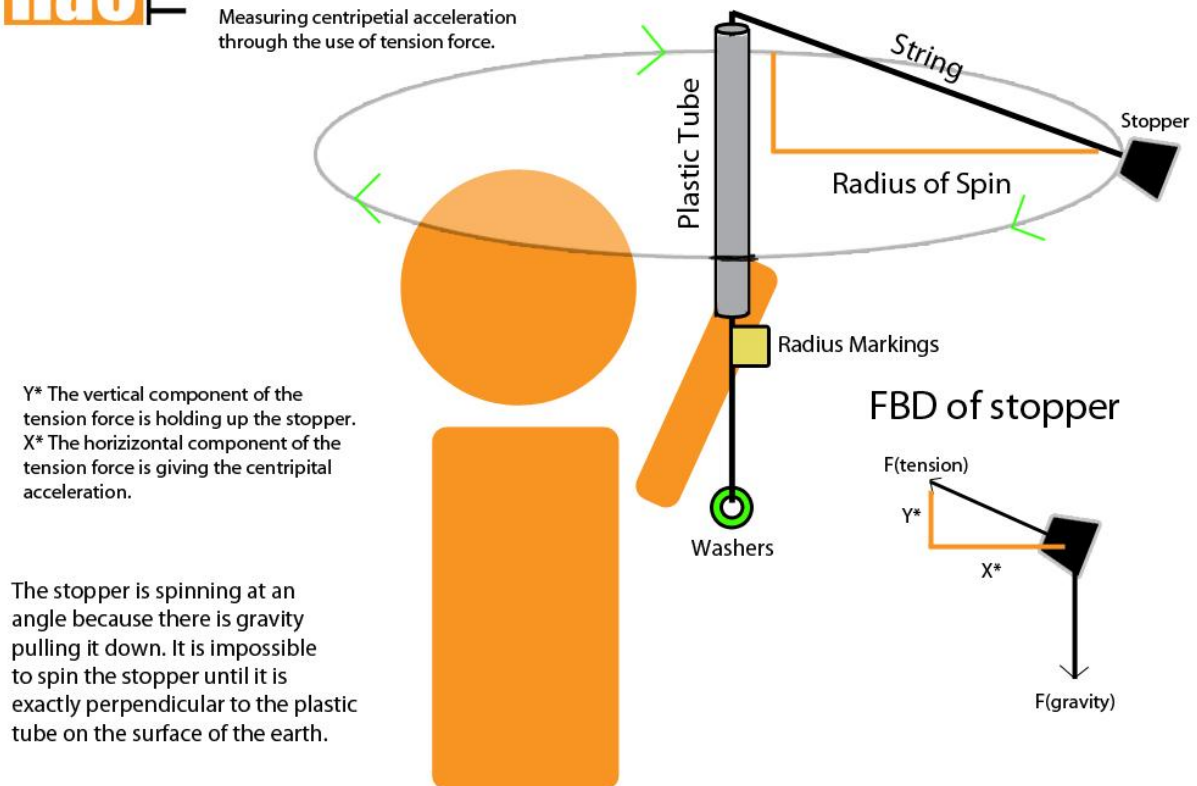
Figure 1 This diagram is showing the setup of our apparatus which also includes a FBD of the stopper. The math within our lab report are based on the grounds that the stopper is exactly perpendicular to the plastic straw.

The lab is done through the use of a string that has one end tied to a rubber stopper and the other tied to a number of washers. After, we used a meter stick to mark out our fixed radius position by sticking a piece of tape on to the string. The string is then feed through a plastic tube/straw, and then given the washers are placed on accordingly. The plastic straw is then spun by the hand until the marking on the string has moved to directly under the straw and is no longer fluctuating in position. Once the marking no longer moves our 3 timer's countdown to begin timing for the 20 revolutions.

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Data

Mass of the rubber stopper: 0.0056 kg

Mass of a single washer: 0.0137kg

Data Table for Centripetal Force Lab

Radius (m)	# of Washers	Time it Took for 20 Revolutions (s)			Average Time (s)	Force of Tension(N)
		Trial 1	Trial 2	Trial 3		
0.2	4	13.56s	13.03s	12.61s	13.07s	0.21952n
	6	11.11s	11.01s	11.09s	11.07s	0.32928n
	8	10.45s	10.32s	10.69s	10.49s	0.43904n
	10	10.30s	10.22s	10.70s	10.41s	0.5488n
	12	9.18s	9.12s	9.16s	9.15s	0.65856n
	14	9.12s	9.12s	8.77s	9.00s	0.76832n
	16	7.84s	7.96s	8.15s	7.98s	0.87808n
	18	7.31s	7.39s	7.28s	7.33s	0.98784n
0.3	8	12.44s	12.64s	12.35s	12.48s	0.43904n
	10	12.30s	12.21s	12.36s	12.29s	0.5488n
	12	10.12s	10.00s	10.03s	10.05s	0.65856n
	14	9.47s	9.53s	9.74s	9.58s	0.76832n
	16	9.66s	9.20s	9.05s	9.30s	0.87808n
	18	9.09s	9.03s	9.35s	9.16s	0.98784n
	20	8.57s	8.21s	8.27s	8.35s	1.0976n

Table 1 This table displays all the data that was collected during the lab. Notice the change in radius.

Data Analysis

The data we collected shows that as the number of washers increase, the rubber stopper needs to be spun faster in order to keep the radius of the circular motion constant. It also verifies that the period will be smaller if the centripetal force increases, and that these two variables have an inverse ratio. As shown we have 3 time trials of each difference tension force, this helps with the elimination of errors that can be caused when conducting the lab.

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Graphical Analysis
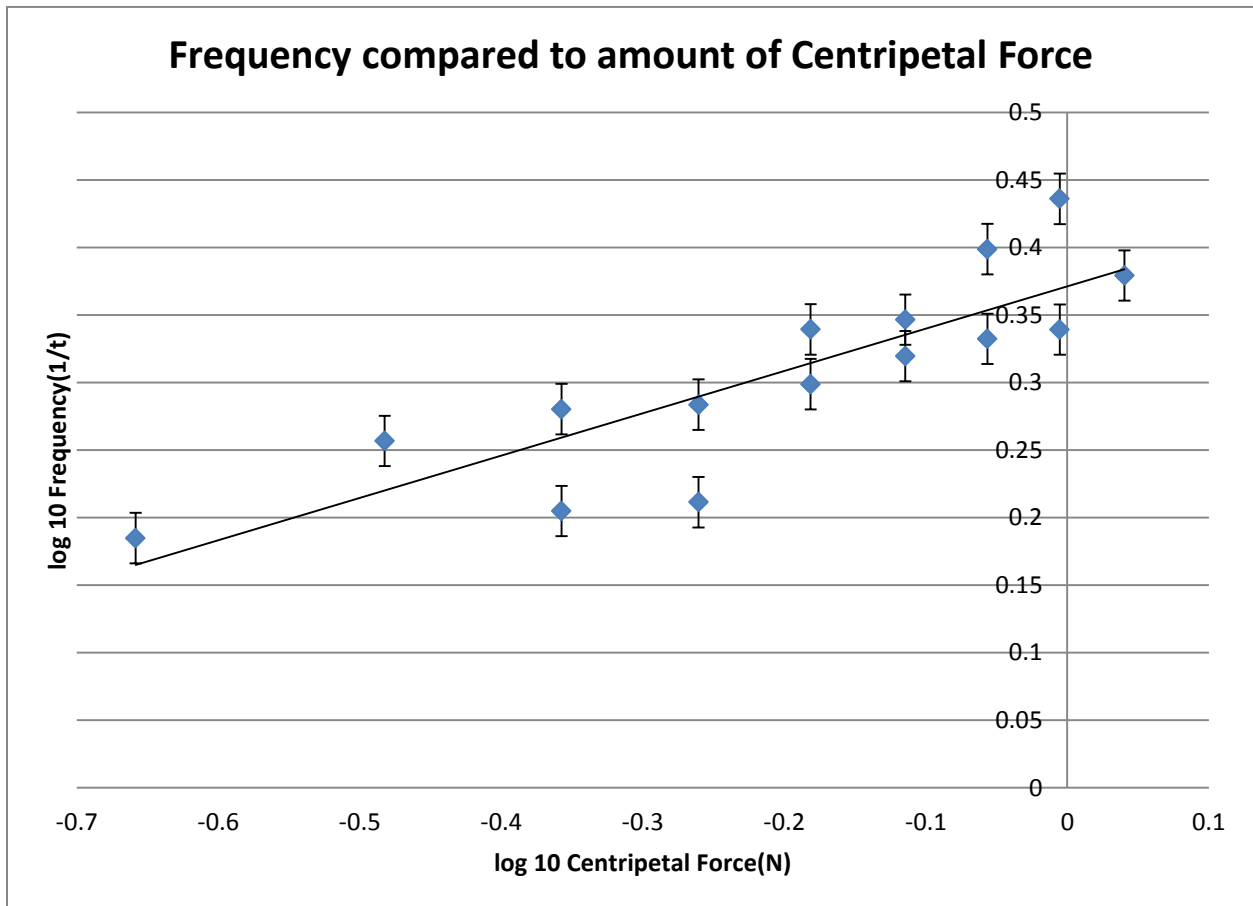

Frequency compared to amount of Centripetal Force

Table 2 Shows the plotted data of Frequency to log10 to the centripetal force to log10 which has an equation of y = 0.3133x + 0.3713

As seen the graph we can conclude that our experiment's hypothesis is conclusive to the data collected. The graph shows a linear slope of 0.313 which is quite far from the expected 0.5, but this could have been the result from the fact that the angle that of which the tension force pulling on the stopper was not directly perpendicular to the plastic straw. The graph also shows centripetal force well in to the negative, which is the result of using smaller than 1 numbers on a log graph, therefore the data is deemed feasible. Some of the plotted data is well out of the error range which is expected from the inconsistent spinning of the mass and other errors that could have caused undesired data, all errors are explained in the conclusion.

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Conclusion

In conclusion, our hypothesis was correct. The centripetal acceleration and the angular speed of an object do have a square root relationship during a uniform circular motion. Because the angular speed increases as the centripetal acceleration increases and vice versa, they also have a direct relationship between them.

Within this experiment systematic and human errors during the lab greatly impacted the data collected and this is a list of known errors that was at fault:

- The random error of keeping the rubber stopper in motion at a constant speed. To reduce this error, our group ensured that the rubber stopper was spinning at a constant speed before counting the number of revolutions.
- The error of keeping the string that was attached to the rubber stopper perpendicular (horizontal) to the hanging mass, refer to figure 1 for details. This resulted in a radius that was smaller than the measured radius. This could have been slightly eliminated if we spun the stopper at a much faster frequency.
- The random error of the weight of the washers not being the same. Some of the washers were slightly heavier and lighter than others.
- The random error of the pipe sliding up and down the string while the rubber stopper was in motion. This resulted in a slightly smaller or larger radius since the string length was reduced or increased. To reduce this error the person holding the pipe ensured that they had a good grip on the pipe to ensure the pipe was not sliding up and down during motion.
- The random error of keeping the hanging washers at rest. The motion of the washers affected the tension and made it not equal to the weight of the washers.
- The systematic error of the pipe and string not being frictionless. This resulted in a reduction of velocity since kinetic friction was acting against the attempted motion.
- The human error of reaction time while timing the time it took to complete 20 revolutions. This error was reduced by having three people time how long it took to complete 20 revolutions.
- The human error of counting the number of revolutions. Because the rubber stopper was rotating so fast, it was hard to accurately count how many revolutions had passed.

If we were to complete the circular motion lab again, we would:

- Try to measure the radius while the rubber stopper was in motion to ensure that the actual radius matched the measured radius.
- Try to avoid shaking the washers as much as possible while the rubber stopper was being spun.
- Try to collect data after the rubber stopper has been spun for a while to ensure the rubber stopper is in a proper circular motion and the radius is kept constant.
- Try to determine the relationship between the frequency of revolution and the radius or mass of an object in a circular motion.

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