Centripetal Force Lab

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1 Abstract

This experiment sought to verify the theoretical relationship between centripetal force, mass, angular velocity, and the radius for a mass traveling in a circular path. Masses were attached to a string which was threaded through a tube to allow one mass to rotate freely while the other hung below. When the swinging mass reached a constant velocity, the time was measured for the mass to complete ten rotations. The radius, hanging mass, and number of rotations measured were kept constant. The angular velocity was calculated and compared to the theoretical angular velocity for each set of conditions. The experimental angular velocity values were higher than the theoretical angular velocity values. Several factors were analyzed to determine the reason for the deviation of these values from the theoretical values, but none of the analyzed factors prove to be the reason.

2 Introduction

This experiment seeks to confirm Newton's 2nd Law and the relationship among mass, radius, and angular velocity. Newton's first law states that "If [an object] is at rest, it will remain at rest. If it is moving, it will continue to move in a straight line at a constant speed" [1]. As an object moves in a circular path, the centripetal force is the force that pulls the object in towards the center of the circle. Newton's second law states that "A force applied to an object causes the object to accelerate and the acceleration is in the direction of the net force" [1]. This law is often written as

$$F_{net} = ma$$

where the net force acting on the object is equal to the mass times the acceleration. In this experiment, the centripetal force is equal to the tension of the string, thus

$$F_{cent} = T = m_1 a$$

We also know that the tension is equal to the hanging mass, so we can conclude

$$T = m_2 g$$

where m_2 is the hanging mass. The centripetal acceleration is the acceleration of an object moving in a circular path. For uniform circular motion, the centripetal acceleration is given by

$$a_c = \frac{v^2}{r}$$

When an object moves in a circular path, its velocity is given by

$$\omega = \frac{2\pi}{t}$$

where t is the time for one rotation, and ω is given in radians/sec. According to Newton's 2nd Law, the angular velocity can be calculated as follows.

$$T = m_1 a$$

$$m_2 g = m_1 r \omega^2$$

$$\omega^2 = \frac{\frac{m_2}{m_1} g}{r}$$

$$\omega = \sqrt{(\frac{g}{r})(\frac{m_2}{m_1})}$$

3 Materials and Methods

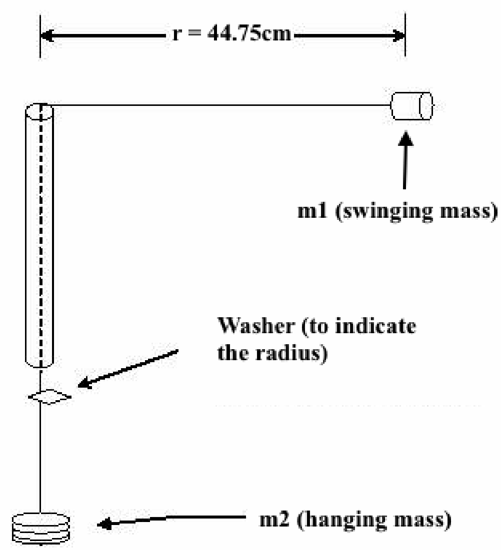

Figure 1: The experimental design.

Figure 1 demonstrates the apparatus used in the experiment. A 100-gram mass was tied to one end of a string (m_2). A washer was attached to the middle of the string and the free end of the string was threaded through a plastic tube. The string was then tied to a second mass which varied in weight(m_1). The swinging mass was wrapped in Styrofoam and tape to ensure safety. The radius of m_1's circular orbit was measured by measuring the length of the string from the center of m_1 to the edge of the plastic tube.
One student, Iris, held the plastic tube and swung m_1 in a circular orbit until it reached a constant speed and was parallel to the floor. Two students then measured the time for the mass to complete ten rotations, and the students' times were averaged and recorded. Ten trials were completed for each swinging mass. The process was repeated and the mass of m_1 was varied (11.2, 25.0, 31.0, 36.0, 45.5, 50.5, and 56.0 grams). The radius was kept constant by swinging the apparatus at a speed that allowed for the washer to rest just below the plastic tube, as this was the position of the washer when the radius was measured.

4 Data

Table 1 lists the average time recorded for 10 rotations, the time for 1 rotation, the calculated experimental ω, and the theoretical ω values for each swinging mass. The average of the recorded times was divided by 10 to determine the time for a single rotation. The experimental angular velocity was calculated using $\omega = \frac{2\pi}{t}$ where t is the time for one rotation. The theoretical angular velocity was calculated using $\omega = \sqrt{(\frac{g}{r})(\frac{m_1}{m_2})}$.

Table 1: Measured times and calculated angular velocities.

Mass (g)	Time Recorded (s)	Time for 1 Rotation (s)	Experimental ω (rad/s)	Theory ω (rad/s)
11.2	4.40	0.440	14.30	13.98
25.0	6.13	0.613	10.20	9.36
31.0	6.29	0.629	9.99	8.40
36.0	6.72	0.672	9.34	7.80
45.5	7.32	0.732	8.58	6.90
50.5	7.88	0.788	7.97	6.60
56.0	8.25	0.825	7.62	6.30

Figure 2 is a graph of the experimental ω values and theoretical ω values from Table 1.

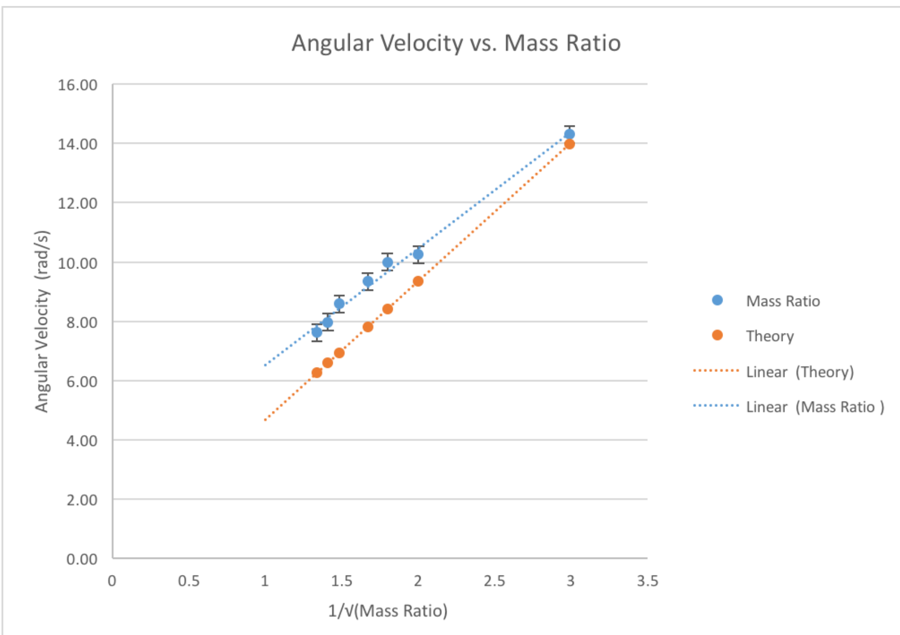

Figure 2: Angular Velocity vs. Corrected 1/ Square Root of Mass Ratio Graph

Standard Deviation error bars were used to account for any errors in timing. The data in the graph was linearized using $\frac{1}{\sqrt{\frac{m_2}{m_1}}}$. The experimental angular velocity values are higher than the theoretical angular velocity values for each of the swinging masses.

5 Results

The experimental data does not confirm Newton's 2nd Law. The experimental ω values are all higher than the theoretical ω values. This indicates there is systematic error present. There is a factor affecting the angular velocity that the theory does not account for, or a systematic performance error.

One error identified is the exclusion of the weight of the washer and string. The hanging mass was recorded as 100 grams, which was the weight of the mass itself. However, the mass of the string and washer were not considered. After weighing the apparatus, it was found that the actual weight of the hanging mass was 105.5 grams. By increasing the hanging mass, the theoretical angular velocity is increased slightly, but not enough to completely correct for the error. Figure 3 demonstrates the adjusted graph after correcting the hanging mass value to 105.5 grams.

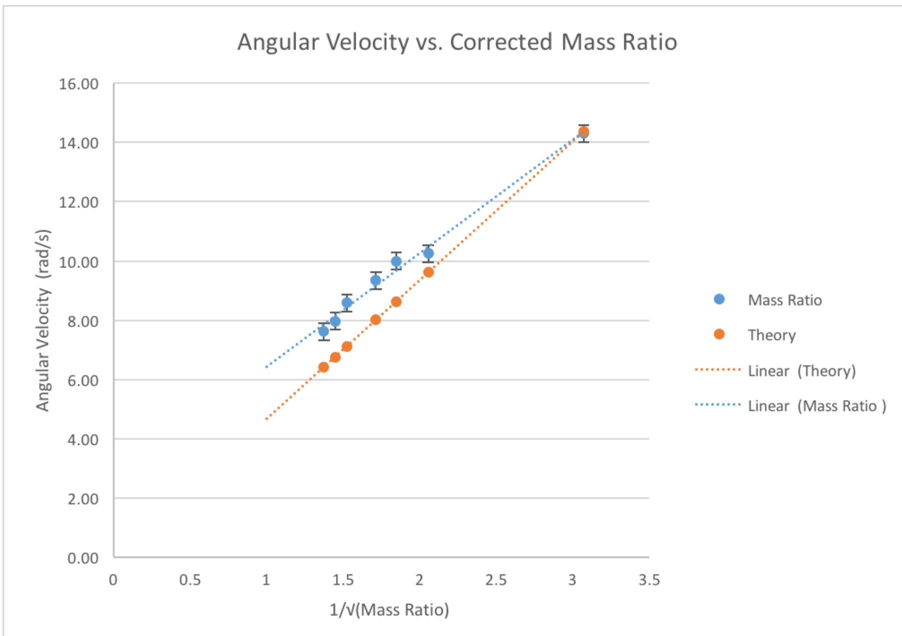

Figure 3: Angular Velocity vs. 1/ Square Root of Mass Ratio Graph

Another possible source of error is the measurement of the radius. To determine what length radius would make the theory equal to the experimental angular velocity, we can solve for r.

$$\omega_{theory} = \sqrt{\frac{9.8}{r}} \frac{1}{\sqrt{massratio}}$$

$$9.61 = \sqrt{\frac{9.8}{r}} \frac{1}{\sqrt{4.22}}$$

$$r = 47.41cm$$

We can see that the radius would have to be about 2.7 cm larger to make the theoretical ω value equal to the experimental ω value. It is possible that instead of measuring the radius from the center of the mass to the edge of the tube, we should have measured from the center of the mass to the far edge of the tube, including the tube's entire diameter. This is because the string will move around the inside of the tube in a circle with the diameter of the tube. Additionally, the

experimental radius of the swinging mass may be larger than measured as the student's hand was moving in a small circular motion to keep the mass in motion. The movement of the student's hand was not accounted for.
It is possible that the tension of the string was not parallel to the ground. In this case, the tension would not equal the mass times gravity, but rather the mass times the cosine of the angle at which the string was angled at. At small angles, this would lead to the theoretical angular velocity being smaller, which only causes the experimental data to be farther from the theory.

6 Conclusion

The experimental data does not confirm Newton's 2nd Law when initially analyzed. By linearizing the data and comparing it graphically to the theoretical angular velocity for each mass, it is clear that the experimental angular velocity values are larger than the theoretical values. It is difficult to determine the actual source of error in this experiment, but it is possible that the theory does not account for sagging of the string, the experimenter's hand increasing the radius, or the air resistance. After correcting the weight of the hanging mass, the theoretical angular velocity values increased slightly, lessening the gap between experimental and theoretical values. This measurement error could have contributed to the variation from theory, but it is not enough to explain for the variation. The measurement of the radius was taken incorrectly, and by including the diameter of the plastic tube and accounting for the student's hand swinging, the theoretical angular velocity values would be closer to the experimental values.

7 Acknowledgements

I acknowledge the assistance of my lab partners, Hannah Ford, Iris Lin, and Calvin Celebuski.

8 Notes and References

Knight, Randall, Brian Jones, and Stuart Field. *College Physics: A Strategic Approach.* 3rd ed. Glenview, IL: Pearson Education, 2015.