Lab Report 11: Center of Mass and Torque

PHY121

November, 18th, 2024

Professor R. Lathrop — Professor M. Petralia

Abereni Opuiyo

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Purpose

To use static equilibrium situations to solve for the center of mass of rigid rods.

Theory

Uniform circular motion is the motion of an object in a circle at a constant velocity. Although the velocity of the object is constant, the direction is constantly changing in the circle, and thus there is acceleration. This specific type of acceleration, wherein the magnitude of velocity is constant but its direction is changing, is called *centripetal acceleration* and is determined with the following equation.

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

$\mathbf{a_c}$: Centripetal acceleration
v : Velocity of object
r : Radius of circle

Since there is an acceleration, there must be a force, so using Newton's Second Law, the formula for the *centripetal force* is given by:

$$F_c = m\frac{v^2}{r}$$

$\mathbf{F_c}$: Centripetal force
m : Mass of object
v : Velocity of object
r : Radius of circle

Velocity is equal to displacement over time. When dealing with circles, the magnitude of displacement will equal the circumference of the circle. Based off that, the formula for velocity of an object on a circular path is given by:

$$v = \frac{2\pi r}{t}$$

v : Velocity of object
r : Radius of object
t : Time for object to complete on revolution on circular path
r : Radius of circle

Procedure

Part 1

1. Measured 20 cm of **string** between **rubber stopper** and **tubing**.
2. Clipped **alligator clip** 1 cm below **tubing**.
3. Tied **mass hanger** and 45 g of weight to **string**.
4. ** Added more **alligator clips** to **string** to prevent it from going into **tubing**.
5. ** Practiced swinging **rubber stopper** in a horizontal circle such that the bunch of **alligator clips** stopped right at **tubing**.
6. Once comfortable with speed of swing, recorded time needed for 20 cycles (complete revolutions) to pass.
7. Calculated time for 1 revolution by dividing time recorded by number of cycles timed for (20).
8. Calculated *centripetal force* using weight of hanging mass.
9. Calculated *average velocity* using *average period.*
10. Repeated steps 3 through 9 for 60 g, 70 g, and 80 g of weight.

Part 2

11. Measured mass of **rubber stopper**.
12. Calculated *expected velocity* for **rubber stopper** using its measured mass.
13. Determined *percent error* between expected and *measured period.*

Part 3

14. Placed 70 g on 5 g **mass hanger**.
15. Measured 0.1 m for length of **string** between **rubber stopper** and **tubing**.
16. Repeated steps 4-9 for 0.15 m, 0.2 m, and 0.3 m.

** **INCORRECT**: Deviated from lab instructions. The tubing string was supposed to be swung at a speed such that the alligator clips stayed 1 cm below the tubing.

Calculations & Graphs

Tangential Velocity

$$v = \frac{2\pi r}{t} \tag{1}$$

v : velocity
r : radius of circle
t : time for 1 revolution

Sample Calculation

using part 1 data with 50 g of weight

$$\begin{aligned} v &= \frac{2\pi r}{t} \\ &= \frac{2\pi(0.2 \text{ m})}{0.3426 \text{ s}} \\ v &= \boxed{3.666 \text{ m/s}} \end{aligned}$$

Centripetal Force

$$\mathrm{F_c} = \frac{mv^2}{r} \tag{2}$$

$\mathbf{F_c}$: centripetal force
m : mass of object
v : tangential velocity of object
r : radius of circle

Sample Calculation

using expected velocity in part 2 with 50 g

$$\begin{aligned} \mathrm{F_c} &= \frac{mv^2}{r} \\ &= \frac{(0.012 \text{ kg})(2.858 \text{ m/s})^2}{0.2 \text{ m}} \\ \mathrm{F_c} &= \boxed{0.49\,\mathrm{N}} \end{aligned}$$

Average Value Formula

$$\overline{a} = \frac{\text{sum of values}}{\text{total \# of values}}$$

Sample Calculation
average period using Part 1 at 50 g

$$\overline{a} = \frac{\text{sum of values}}{\text{total \# of values}}$$

$$= \frac{0.334\text{ s} + 0.3515\text{ s}}{2}$$

$$\overline{a} = \boxed{0.3426\,\text{s}}$$

Percent Error

$$\text{PD} = \left|\frac{\text{measured - actual}}{\text{actual}}\right| \text{ x } 100\% \tag{3}$$

Sample Calculation
percent error between theoretical period and measured period using values from part 3

$$\text{PD} = \left|\frac{\text{measured - actual}}{\text{actual}}\right| \text{ x } 100\%$$

$$\text{PD} = \left|\frac{0.3426\text{ s - }0.5071\text{ s}}{0.5071\text{ s}}\right| \text{ x } 100\%$$

$$PD = \boxed{32.41\%}$$

Tables

Table 1: Part 1

Mass (kg)	0.05	0.06	0.07	0.08
Trial 1 Period (s)	0.334	0.329	0.332	0.359
Trial 2 Period (s)	0.3515	0.353	0.354	0.3295
Average Period (s)	0.3427	0.341	0.343	0.3442
Average Velocity (m/s)	3.666	3.685	3.663	3.65
Expected F_c (N)	0.49	0.588	0.686	0.784
Actual F_c (N)	1.072	1.083	1.07	1.062

Table 2: Part 2

Mass (kg)	0.05	0.06	0.07	0.08
Theoretical Velocity (m/s)	2.478	2.715	2.932	3.135
Theoretical Period (s)	0.5069	0.4627	0.4284	0.4007
Actual Period (from part 1) (s)	0.3427	0.341	0.343	0.3442
Percent Error	32.39	26.31	19.94	14.1

Table 3: Part 3

Radius (m)	0.1	0.15	0.2	0.3
Trial 1 Period (s)	0.273	0.7	0.5015	0.5625
Trial 2 Period (s)	0.252	0.4575	0.5015	0.568
Average Period (s)	0.2625	0.5787	0.5015	0.5652
Expected Velocity (m/s)	2.146	2.629	3.035	3.718
Average Velocity (m/s)	2.393	1.628	2.505	3.335
Percent Error Velocity (%)	11.50	38.07	17.46	10.30
Expected F_c (N)	0.735	0.735	0.735	0.735
Actual F_c (N)	0.9133	0.2818	0.5004	0.5913
Percent Error F_c (%)	24.25	61.65	31.91	19.55

Graphs

Figure 1: Part 1: Actual F_c vs Actual Average Velocity

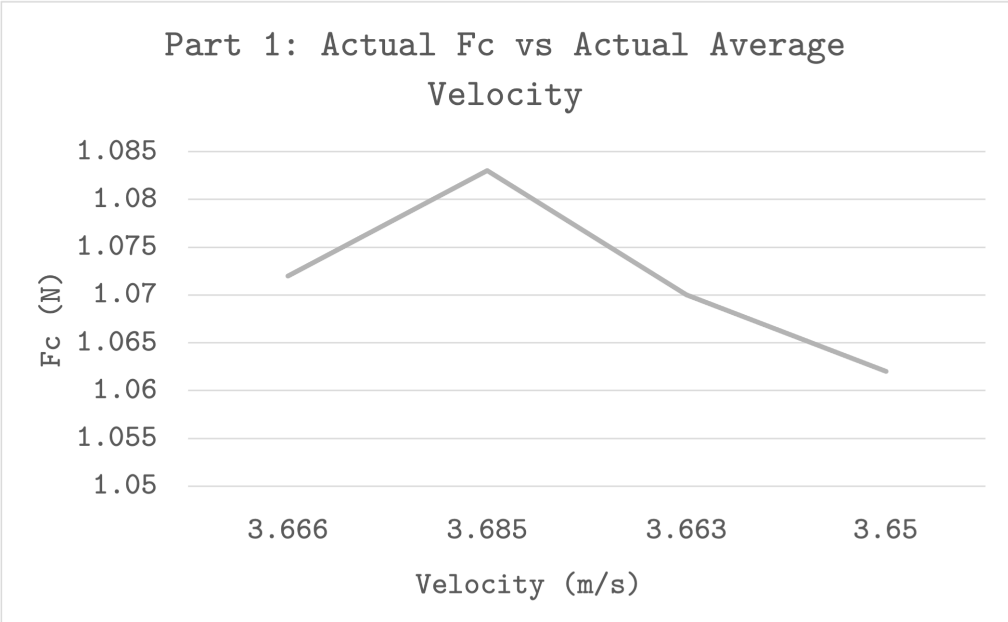


Figure 2: Part 1: Expected F_c vs Expected Velocity

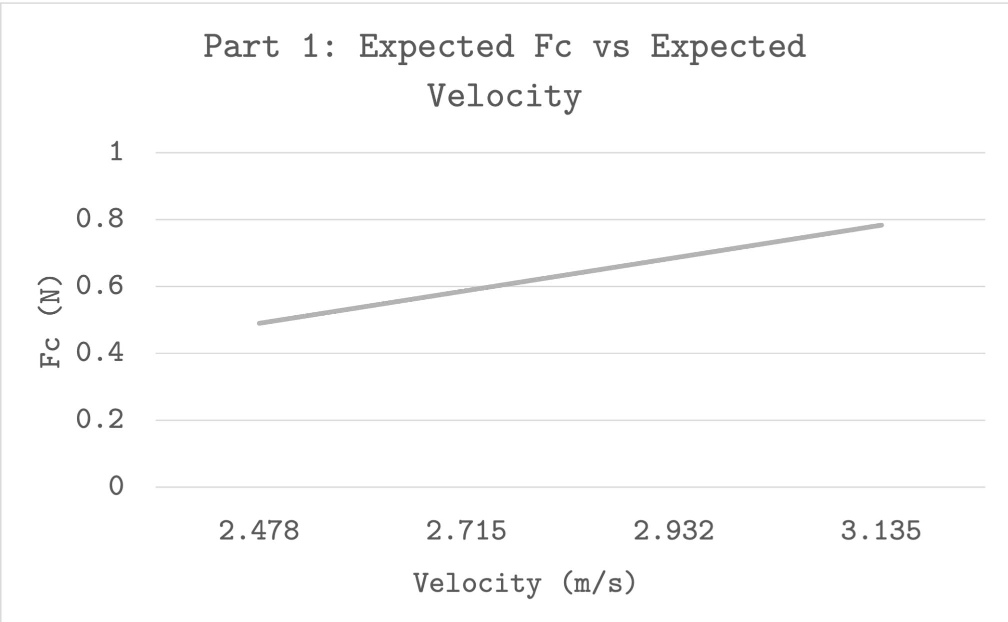


Figure 3: Part 3: Radius vs Actual Average Velocity

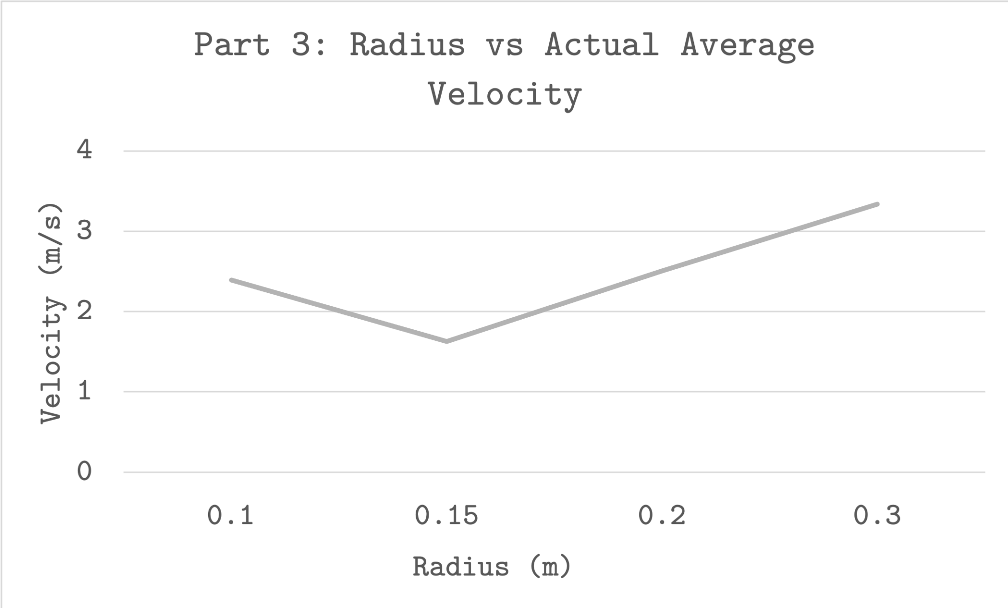
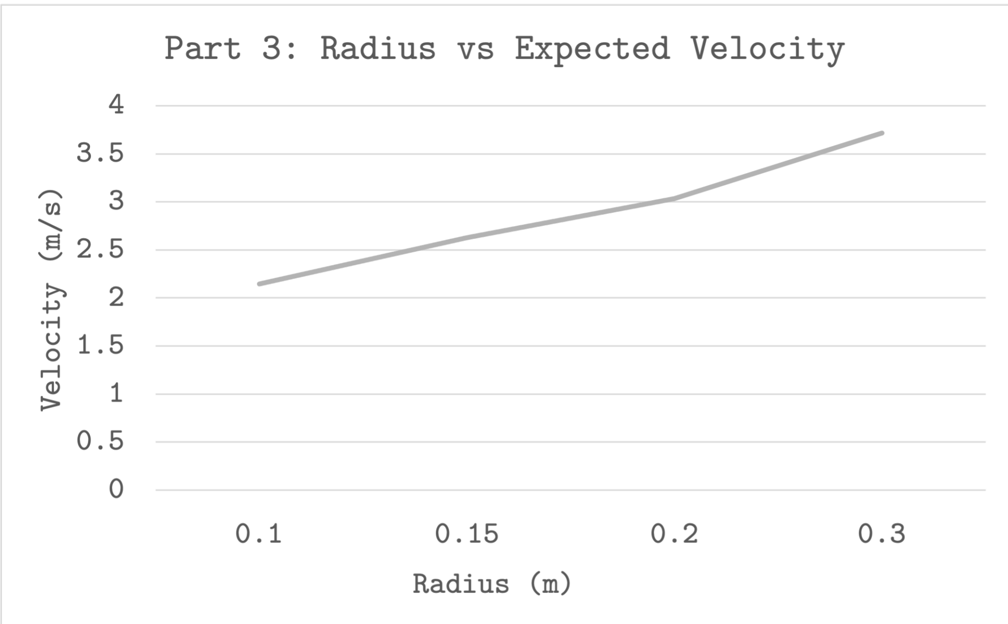


Figure 4: Part 3: Radius vs Expected Velocity



Questions

1. **Should the 100 grams be placed closer or further away from the pivot point when compared to the 60 grams?**

   We had more trouble with the lighter masses.

2. **How does the calculated value compare to the experimental value you found? (Percent error)**

   The biggest source of error in the lab was not following directions properly. Instead of swinging the rubber stopper such that the alligator clip remained 1 cm below the tubing, we attached MORE alligator clips and swung the stopper such that the centripetal force exceeded the weight of the stopper below. Our measured velocity ended up being way higher and consistent than it should have been.

3. **How does the calculated value compare to the experimental value you found? (Percent error)**

   Since we didn't follow directions properly in part 1, part 3 ended up being the most difficult. I think this was the case because as the radius increased, we needed to find the right speed to balance the weight of the hanging mass at the bottom. We got close but the results would have aligned with our expectations more if we practiced doing the experiment properly the first time.

4. **Where do you need to place the knife edge such that the meter stick would be balanced?**

   Our own data shows no correlation, but using algebra, we'd expect the centripetal force to increase as the velocity increased.

5. **Explain in your own words why the meter stick needed to be shifted to find the new balance point. How can the system balance with one mass placed on it?**

6. **Describe the procedure that you used to find the center of mass.**

7. **What can you deduce about the distribution of mass inside the non uniform rod? (Is one side heavier than the other? How does that affect finding the center of mass?)**

Conclusion

The purpose of this lab was to test the conservation of mechanical energy. In a system where no non-conservative forces, such as friction, exist, the change in potential energy of an object should equal its change in kinetic energy. To remove the force of friction as much as possible, a glider was placed on an air track. Under these conditions, we attempted to measure the kinetic energy of the glider between two photogates on the track, and compared it with its calculated gravitational potential energy. We also attempted the measure the impact of mass on the conservation of mechanical energy, and increased add 100 grams of mass to the glider with each trial. Our results were interesting.

The time elapsed between the photogates had a low standard deviation across all our trials, meaning our measurements were precise (see Table **??**). Using equation's **??**, **??** and **??** we measured how much energy was conserved in the system along the track. We found that across all our trials, the percent difference between the gravitational potential energy and the change in kinetic energy was at least 27% (see Table **??**). The consistency of these percent differences suggests two things: firstly, changing the mass did not significantly influence the amount of energy conserved, and secondly, there was some external force, factor, or systemic error that contributed to the difference in energy.

If we look at the equations for change in kinetic and potential energy and set them equal to each other, it makes sense that mass has no influence on the conservation of energy since it gets cancelled out (see equation's **??** and **??**). Velocity and height are the remaining variables in the equations that could impact the conservation of energy. If we assume our measurements for the gravitational potential energy are correct, then it's highly possible the source of the energy differences lies within the measured kinetic energy. The kinetic energy of the glider that was measured and calculated, consistently had an absolute value that was higher than the calculated gravitational potential energy (see Table **??**). Based off our analysis of equations **??** and **??**, we can rule out mass and focus on velocity. A greater velocity results in a greater kinetic energy.Giving the glider a head start on the air track, or incorrectly measuring he distance between the photogates for equation **??** could have resulted in greater velocity and influenced our calculations for kinetic energy.

If assume that our measurements for kinetic energy are correct, that the distances between the photogates were accurately measured, and that the glider was not given a head start on the air track, then, ruling out mass, the source of the energy differences would lie in the height measured for the gravitational potential energy calculation. Gravitational potential energy is directly correlated with the height of an object, so a lower height would result in a lower potential energy. Under the assumption that the kinetic energy measurements are correct, it's possible the heights measured for photogate 1 and 2 are lower than they should be, resulting in a lower gravitational potential energy.

Were I to conduct this experiment again, there are a few things I would change to minimize the difference in energies. In order to prevent the possibility of giving the glider a head start, some sort of locking mechanism would need to be added to the air track such that the glider does not need to be let go by human hands. Thereby the initial velocity of the glider is set almost exactly to zero, and the air track is given enough time to negate friction. Regarding measurements, a locking mechanism could also be applied to the photogates, not only to make the time between gates even more consistent, but also to make the starting points for our measurements easier. There was difficulty determining exactly where to start and stop the measurements for the heights of the photogates because of the slanted angle of the air track, so having a locking mechanism would reduce the ambiguity of the measurements.