Phys 11A – Eiteneer
Lab 11 Write-up

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Introduction: The last scheduled lab for the semester is the angular momentum lab. This lab consists of a puck sliding on a home-built air hockey table while tied at its center of mass to a central peg with an extendable rubber band, as described in the lab manual. As the puck moves, it changes its distance from the peg and its linear velocity; however, with virtually no friction, and as the rubber band exerts a central force on the puck, the angular momentum should be conserved, as no net torque is exerted on the puck. Our job is to confirm this.

Please answer the following questions. The answers can be hand-written or typed.

1. In <u>two or three sentences</u>, explain how this experiment is conducted. As in, summarize the procedure.

A puck will be attached to a rubber band that is also attached to a center post. The puck will be pushed and traveling on a horizontal air table in such a way that it not only orbits the center post, but also "bounces" with respect to the center post as well. While this is happening, a strobe light and camera on top will capture the results for us to use.

2. Why do we not care about the "details" of the force exerted by the rubber band?

The rubber band itself does not exert a torque on the puck. If you observe the motion of the puck, you can see that torque will be a vector pointing from the post to the puck and that force will be along the rubber band. If you were to take the cross product of those two vectors, you would notice that they are anti-parallel, so they would cancel out to "0". The torque would be 0 and if that is the case, then we should find that angular momentum is conserved.

3. In your own words, summarize/explain the meaning of conservation of angular momentum. No equations!

Conservation of angular momentum is something that will always be maintained as long as there is no net external torque on the spinning or orbiting object itself. It can be measured in two ways. The first way is to multiply the radius and linear momentum of an object (how fast the object is going times its mass). The second way is to have the moment of inertia multiplied by the angular velocity.

4. What are the "convenience units" of mass, time, length, and angle, used in this lab? Note: do not make any conversions of units in this lab.

The convenience units of mass, time, length, and angle are 1 puck, 1 flash of strobe, 1 inch on the graph paper (referred to as a grinch), and 1 degree.

5. What are the units of angular momentum, in these "convenience units"?

Traditionally, we have kilogram metres squared per second, so in this case we would say puck-grinches squared per flash.

6. Fill in the Excel table provided to you by the instructor. You need to measure the distance from the center of the trajectory to the center of the puck for all 16 positions (r_t, measured in grid-inches), and the angle for all 16 positions (φ, measured in degrees). The Excel calculations are already done for you (15 calculations since calculations of r and Ω require the next value as well). The units of Ω have also been converted to rad/flash, so you don't have to worry about that.

t [flash]	r_t [grinch]	φ [degree]	r = 1/2*(r_t + r_t+1) [grinch]	Ω = Δφ/Δt [rad/flash	L =r^2*Ω [units]	δL [units]
0	4.5	-12	4.200	0.192	3.387	0.174
1	3.9	-1	3.675	0.227	3.064	0.144
2	3.45	12	3.300	0.314	3.421	0.141
3	3.15	30	3.130	0.332	3.249	0.134
4	3.11	49	3.300	0.279	3.041	0.132
5	3.49	65	3.745	0.244	3.427	0.153
6	4	79	4.250	0.175	3.153	0.174
7	4.5	89	4.625	0.140	2.987	0.198
8	4.75	97	4.750	0.140	3.150	0.208
9	4.75	105	4.550	0.157	3.252	0.194
10	4.35	114	4.075	0.192	3.188	0.165
11	3.8	125	3.550	0.244	3.079	0.140
12	3.3	139	3.125	0.349	3.409	0.138
13	2.95	159	3.000	0.349	3.142	0.131
14	3.05	179	3.275	0.314	3.370	0.139
15	3.5	197				

Measurement uncertainties		
δr [grinch]	δφ [deg]	δΩ [rad/flash]
0.05	0.5	0.009

Done.

Think about the uncertainty in measuring r_t and φ, and fill in the uncertainty table, also provided in Excel.

Done.

7. Derive the equation for uncertainty in angular momentum, δL, using the error propagation technique. Remember, $L = r^2\Omega$, and that uncertainty $\delta\Omega = \delta\phi \cdot \frac{\pi}{180}$. Assume that the mass of the puck (= 1 puck) is exact, and the time between flashes (= 1 flash) is exact.

$$L = m r^2 \Omega \quad \text{or} \quad L = r^2 \Omega$$

$$r = \frac{1}{2}(r_t + r_{t+1}) \leftarrow \delta r = \sqrt{\left(\frac{1}{2}\delta r_t\right)^2 + \left(\frac{1}{2}\delta r_t\right)^2}$$

$$= \frac{1}{\sqrt{2}} \delta r_t$$

$$\Omega = \frac{\varphi_{t+1} - \varphi_t}{\Delta t} \leftarrow \delta \Omega = \sqrt{2} \frac{\delta \varphi_t}{1/\text{fps}}$$

$$\delta L = \sqrt{\left(\frac{\partial L}{\partial r} \cdot \delta r\right)^2 + \left(\frac{\partial L}{\partial \Omega} \cdot \delta \Omega\right)^2}$$

$$\frac{\partial L}{\partial r} = m \Omega \frac{\partial}{\partial r}(r^2) = 2 m \Omega r \qquad \delta \varnothing \cdot \frac{\pi}{180}$$

$$\frac{\partial L}{\partial \Omega} = m r^2 \frac{\partial}{\partial \Omega}(\Omega) = m r^2$$

$$\delta L = \sqrt{\left(2 m \Omega r \cdot \frac{1}{\sqrt{2}} \delta r_t\right)^2 + \left(m r^2 \cdot \sqrt{2} \frac{\delta \varphi_t}{1/\text{fps}}\right)^2}$$

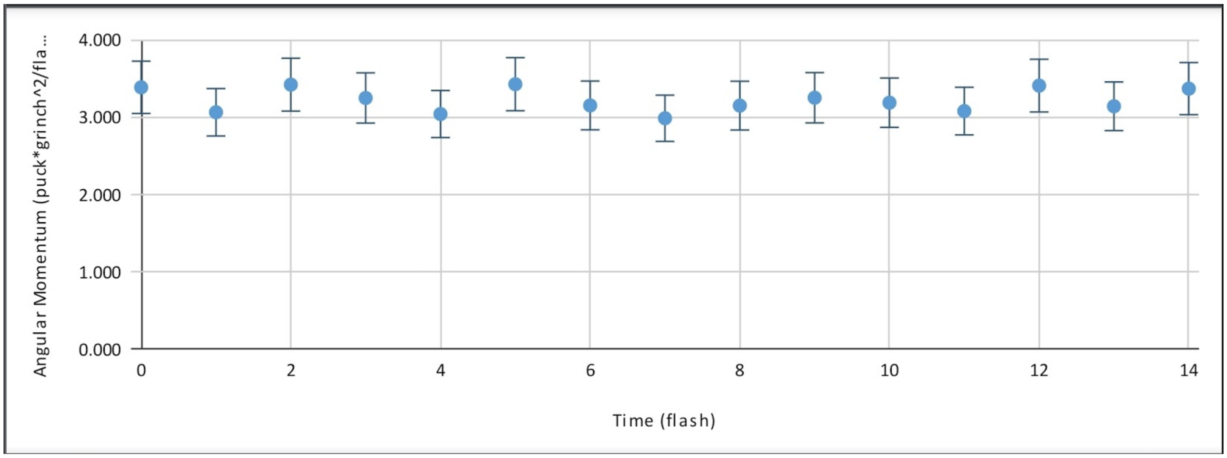
$$\boxed{\delta L = \sqrt{\left(2 m \Omega r \cdot \frac{1}{\sqrt{2}} \delta r_t\right)^2 + \left(m r^2 \cdot \sqrt{2} \frac{\delta \varphi_t}{1/\text{fps}} \cdot \frac{\pi}{180}\right)^2}}$$

8. Calculate the average value of angular momentum L, and the average value of uncertainty, δL (use Excel). Record the final answer here (don't forget units):

$L_{avg} \pm \delta L_{avg} =$ **3.45 ± 0.17 puck-grinches squared per flash**

9. Is total angular momentum conserved during the experiment (use your data to answer this)? Why or why not?

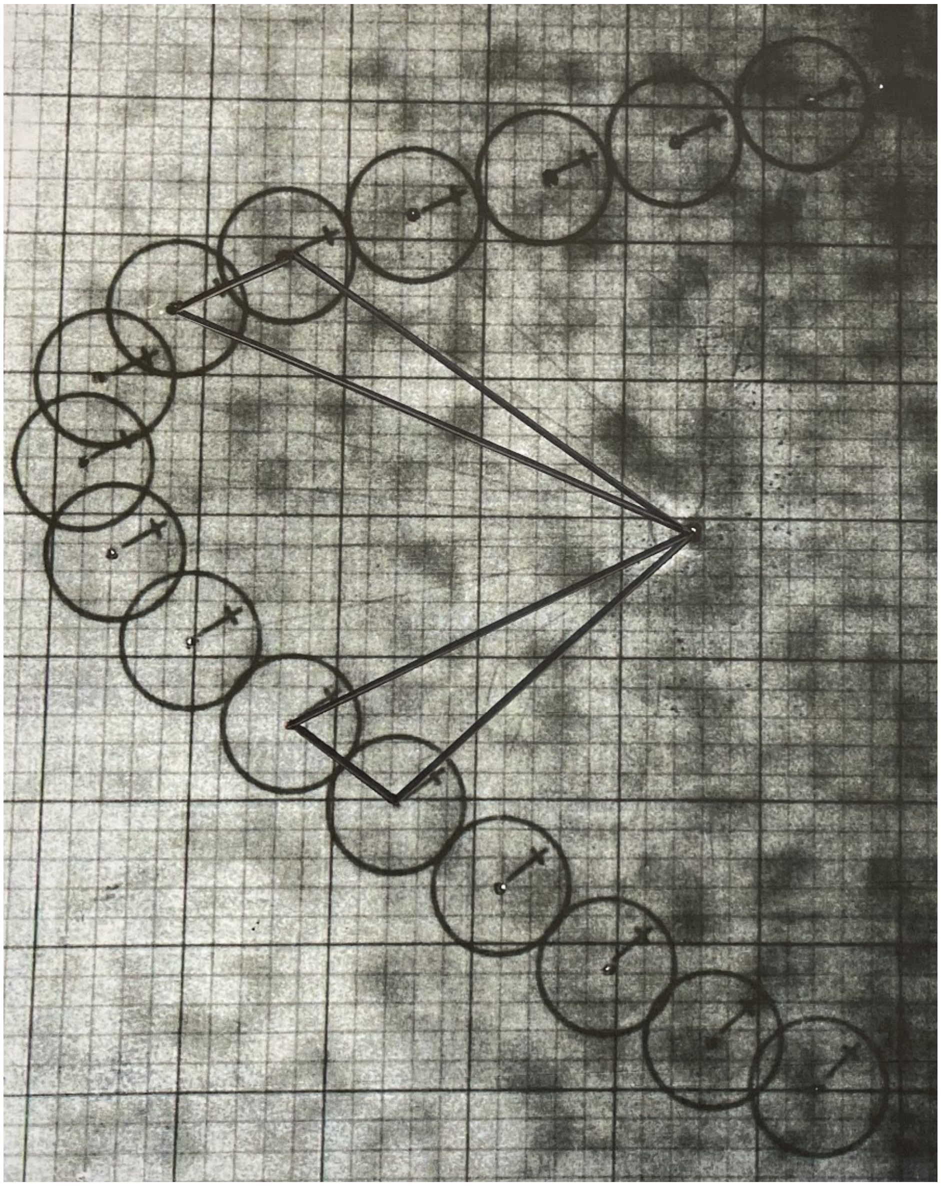
Total angular momentum is in fact conserved throughout the experiment. If you look at the scatterplot, you can see that all of the data points overlap within their uncertainty. What this means is that you can draw a straight line through the uncertainty of the points and not have the line "break" between points. What this means is that there is no noticeable change that would lead us to conclude that momentum has not been conserved.



10. Where is the puck moving the fastest? The slowest?

The puck is moving fastest when it is closest to the center post and slowest when it is farthest away from the center post. Please keep in mind that angular momentum is conserved. When the distance from the axis of rotation is reduced, rotational inertia is reduced as well. As such, angular velocity must increase to keep the angular momentum conserved.

11. Pick any two adjacent puck positions, and draw a line connecting the centers. Also draw a two lines, one from each puck position, to the center of the trajectory, thus completing a triangle. Repeat for another two puck positions, at least two or three positions away.



12. Using a ruler, measure the sides of each of the three triangles in cm, and calculate the two areas (in cm^2), using Heron's formula (provided in the lab manual). Show work!

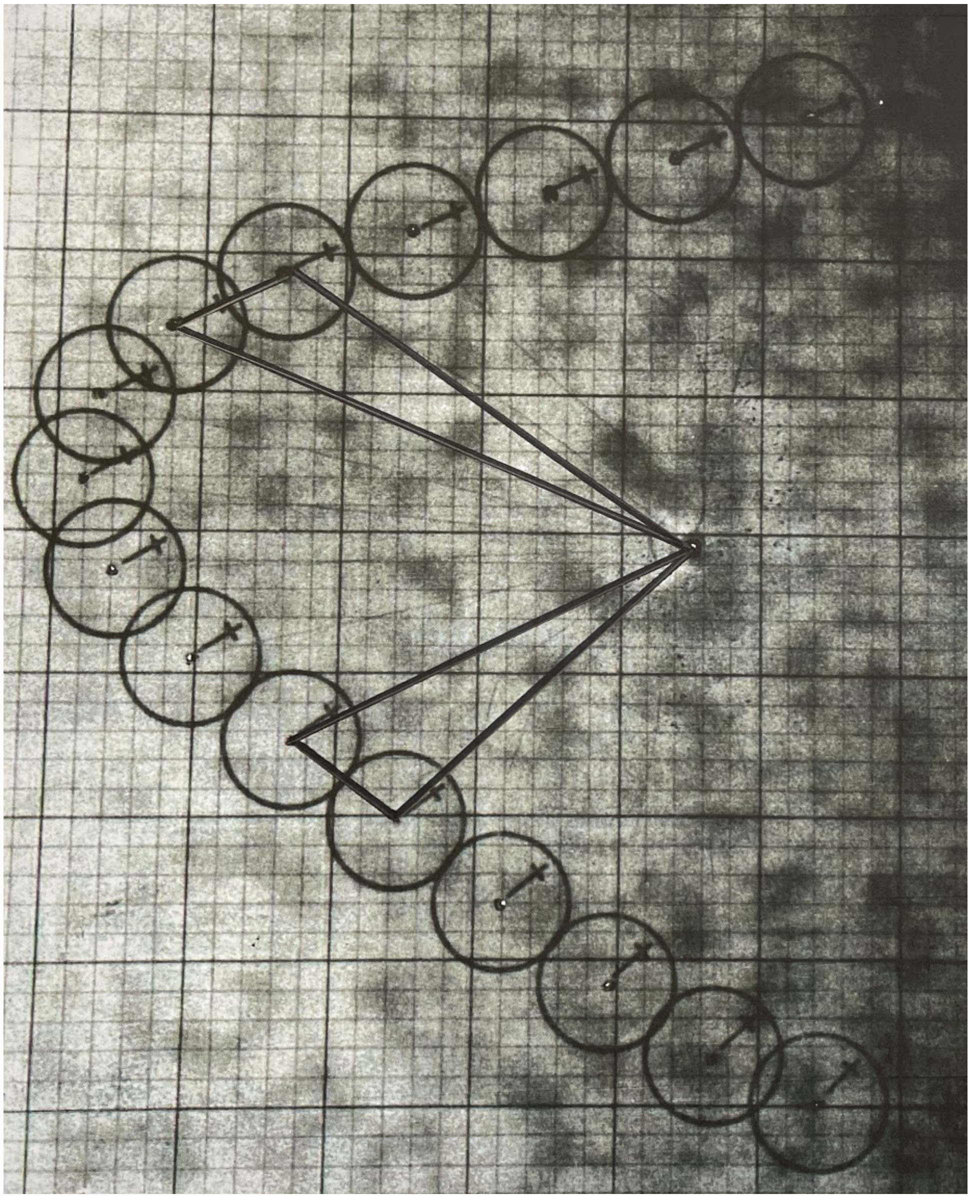
s=½(a+b+c)
Area=[s(s-a)(s-b)(s-c)]^{½}

s_1=½(2.5cm)(7.5cm)(8.2cm)
s_1=76.875cm
$Area_1$=[76.875cm(76.875cm-2.5cm)(76.875cm-7.5cm)(76.875cm-8.2cm)]^{½}
$Area_1$=5219.235cm^2

s_2=½(2.3cm)(9.1cm)(10.5cm)
s_2=109.883cm
$Area_2$=[109.883cm(109.883cm-2.3cm)(109.883cm-9.1cm)(109.883cm-10.5cm)]^{½}

$Area_2$=10881.450cm^2

13. Are these two areas the same? Why or why not? Should they be?



The two areas are not the same and they shouldn't be because the puck doesn't sweep equal areas at all points of the orbit.

14. What could contribute to the errors? List at least 2 or 3 sources of error, specifying whether each of them contributes to random error or systematic error. Note: no credit will be given for listing "human error."

Instrument drift (systematic): In this case, the rubber we had could have been stretched out from multiple uses, skewing our results a bit.

Physical variations (random): So far, the data we had only came from one trial. To be sure that we are right, we could have held multiple trials instead.

What to submit:

- ✔ Your data tables (Excel)
- ✔ Your drawing of the two triangles for Question 13
- ✔ Your answers to these questions
- ✔ Put all your tables, your drawing and answers to these questions in ONE document. Convert this document to PDF form, and submit INDIVIDUALLY, by going to Assignments, Lab 01.
- ✔ This will be due at 6pm ONE week from today.