PHYS101 Lab: Rotational Motion
Instructor: James Cutright

Instructions: Please do not write on this lab. Instead, everything that you do in the lab can be submitted as an excel sheet. You are welcome to email me your excel sheet as your lab submission. In this lab you will be verifying the rotational kinematics that you learned in CH8.

Equipment Needed:

Computer	850 Universal Interface
Standard Mass Set	Thin Black Thread (2 m)
Rotational Motion Sensor	1 Caliper (Entire Class Shares)
Table Top Rod Stand	

Part 1: Rotational Inertia of a Point Mass

Theory: Theoretically, the rotational inertia, I, of a point mass is given by I = MR^2, where M is the mass, and R is the distance the mass is from the axis of rotation (See pictures on next page for experimental set up). Since this experiment uses two mass equidistant from the center of rotation, the total rotational inertia will be:

$$I_{total} = M_{total}R^2$$

In this case M_{total}= M_1 + M_2 ,the total mass of both point masses. We want to be able to calculate the theoretical angular acceleration that the system of 2 point masses should undergo when the weight on the pulley is allowed to drop.
To calculate the net angular acceleration that the system should undergo, we need a few mathematical puzzle pieces. 1) Recall that the torque, τ, applied to the system is equal to :

$$\tau = I\alpha$$

In this case the torque, τ is the torque caused by the weight hanging from the thread wrapped around a pulley and α is the angular acceleration of the system.

2) The torque that is being applied by the mass that is connected to the pulley is calculated with the tension, T, in the thread and the radius, r, of the pulley that you decide to use:

$$\tau = rF = rT$$

3)To calculate the net tension that is being applied to the pulley system, you use newton's laws, from CH4:

$$\Sigma F = mg - T = ma$$

Solving for T, we find that $T = m(g - a)$. In this case "m" is the mass of the mass hanger.

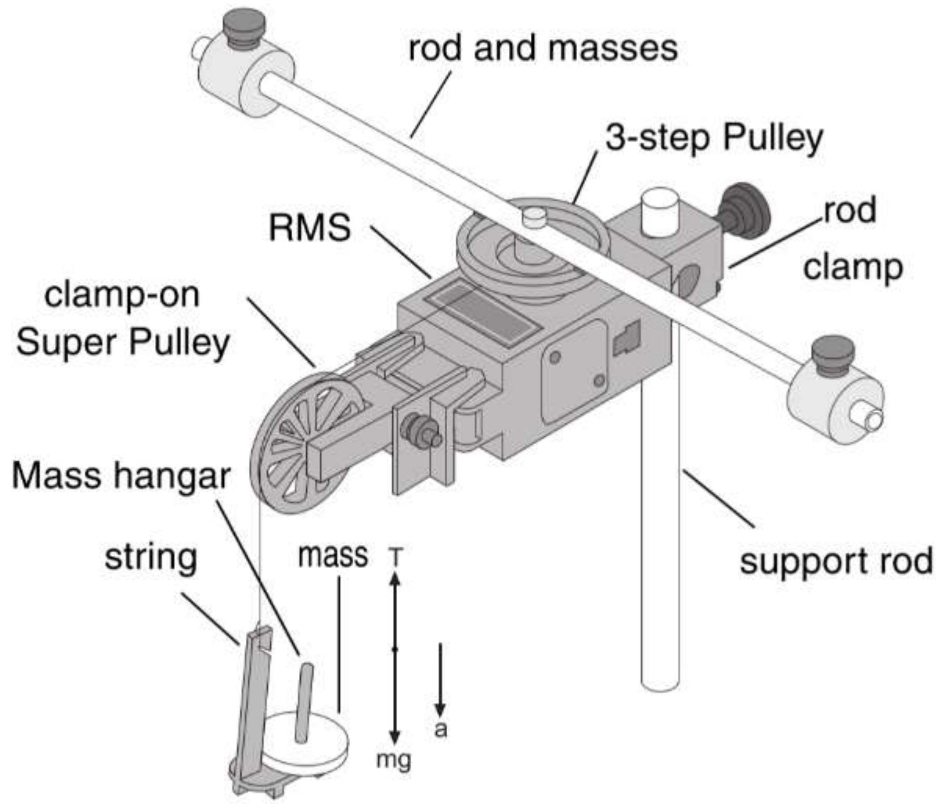


Figure 1.1: Rotary Motion Sensor and Free Body Diagram

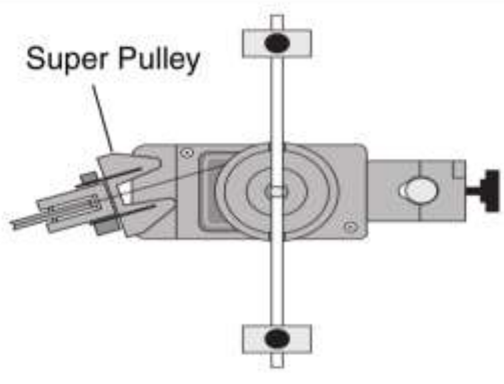


Figure 1.2: Super Pulley Position

4) The angular acceleration and the linear acceleration of the edge of the pulley are related by $a = \alpha r$.

5) We can now rearrange the first equation for torque for the angular acceleration, and then plug in the second equation for torque, and then using the expression for the tension that we found to complete the final expression, as well as the equation for the total inertia of the system. All the step in the algebra are shown, so that you can follow along:

$$\tau = I\alpha = rT$$

$$I\alpha = rm(g - a)$$

$$I\alpha = rm(g - \alpha r)$$

$$I\alpha = rmg - \alpha mr^2$$

$$I\alpha + \alpha mr^2 = rmg$$

$$\alpha[I + mr^2] = rmg$$

$$\alpha = \frac{rmg}{I + mr^2} = \frac{rmg}{M_{total}R^2 + mr^2} = \frac{rmg}{(M_1 + M_2)R^2 + mr^2}$$

This will be the final expression that you can use to calculate the theoretical angular acceleration of the system. You can choose how many steps you do that in, in your excel sheet.

Procedure:

1. Your group will need to build an excel sheet for this experiment's calculations. The entire group can use this sheet and submit it together. There are no "suggested data tables" for this lab. You will decide how to organize your data, calculations, etc. I suggest doing things one step at a time: don't try to do everything in the math all at once. That makes things unnecessarily hard. It also means that I will have a harder time finding mistakes in the equations that you write.
2. Turn on and log in to your computer. Go to the Google Drive and find the folder for Lab 9.
3. Download the lab protocol for Lab 9 and the Capstone Program "PHYS101_Rotational Motion.cap".
4. Attach the rotational motion sensor to the rod stand so that the three-tier pulley is pointing upwards.

5. Connect the sensor to the 850 Universal Interface: yellow goes to digital port 1. Black to digital port 2. Open the program and make sure that the computer can read data from the sensor when you rotate it. You are measuring the angular velocity of the system in rad/s.
6. Measure any masses that you think you will need to measure.
7. Mount the rod with the point masses on to the pulley. Make sure the point masses are each at the same distance from the center of rotation.
8. Use the middle part of the pulley system for this experiment. Measure the size of your pulley. The instructor has calipers you can use to measure the diameter of the pulley. If you aren't sure how to use the calipers, your instructor can help.
9. You should also connect a piece of black thread to the pulley. Note: use a lot of string for this, approximately 2 m, so that you don't have a lot of slack around the system. If you use the notches on the side of the pulley you can secure the string pretty well.
10. Wind the string onto the pulley. Make sure that the string isn't bunched up: this will make the effective radius of the pulley larger.
11. Attach your mass hanger to the string. You will need to decide how much mass you want to put on the system. Note: don't use so little mass that you can't overcome the friction in the bearings of the device.
12. The computer is going to read the angular velocity of the system in rad/s. That means that, if you find the slope of the line that is generated, you should find the angular acceleration of the system. The angular acceleration is what you want to measure, ultimately.
13. You need three separate data runs for each configuration of the point masses. The rough parameters for those data runs are given below. Make sure to complete all three. Using excel to generate your theoretical angular acceleration will make this <u>much</u> easier, since the calculation is a little long, and there are many variables to keep track of. Doing this on a hand calculator will invite small mistakes.
14. Make sure that you compare the theoretical and experimental values for the angular acceleration that you see in your experiment. You will determine how to best do that.

Data Runs:

1. Place the two masses near the ends of the rod, with some amount of mass, m, on the hanger.
2. Move the two masses inwards, toward the middle of the system. Use the same amount of mass, m, on the hanger.
3. Place the masses very close to the center of rotation. Keep m the same here too.

<u>Questions Part 1:</u>

1. Based on your data, are the rotational kinematics of CH8 valid?
2. How could you improve this experiment? Name 3 things in particular that we did not account for.

Part 2: Improving the Experiment in Part 1

Theory: In this part of the experiment you are not actually performing a procedure. Instead, you need to re-analyses your previous data. In excel, copy the first data sheet that you made. Once you have a fresh set of data, look at the net moment of inertia of the system. In the experiment you only accounted for the two “point masses” sitting on the rod. The rod, however, has mass, and therefore a moment of inertia!

Use the table provided on the last page of this lab to calculate what the total inertia of the system should be. This will alter your calculations. You should see that your experimental and theoretical measurements for the angular acceleration of the system get closer to one another.

Questions Part 2:

1. With your new calculations, that take the moment of inertia of the rod into account, you should see some improvement in the data. Is anything else in the experimental system rotating? Did you take into account everything that has a moment of inertia in this experiment.
2. Explain how you could improve the experiment further.

Part 3: Conservation of Angular Momentum

Theory: In this part of the lab you will measure whether the system conserves angular momentum. In theory, if the total angular momentum of the system is conserved. You will have a metal disk attached to the rotational motion sensor, and you will start it spinning. If you then drop some extra mass on top (see diagram below), in the form of a metal disk, then the system should slow down, as follows:

$$\vec{L}_0 = \vec{L}_f$$

$$I_0\omega_0 = I_f\omega_f$$

$$\omega_f = \frac{I_0\omega_0}{I_f}$$

In this case, you will need to calculate the initial and final moment of inertia of the system. This will allow you to determine the final angular velocity based on the initial.

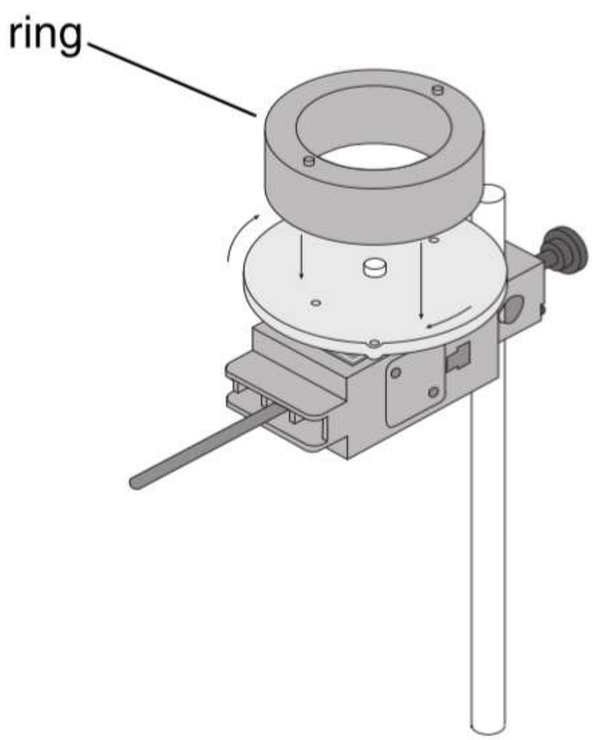


Figure 3.2: Drop Ring on Disk

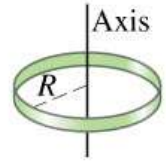
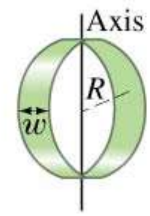
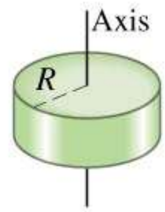
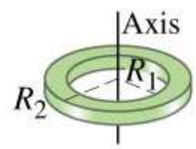
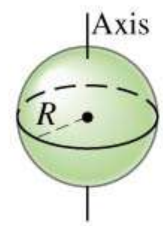
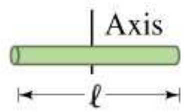
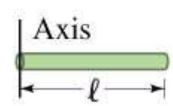
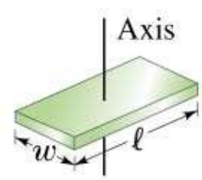
Procedure:

1. Measure any masses that you think you will need. You will need to create an excel sheet that you think will work well for this experiment.
2. Calculate the moment of inertia of the two objects. The table on the last page has the moment of inertias that you will need for this calculation.
3. Start the disk spinning, and gently drop the large black hoop on to of it. Try to line up the centers of the two objects.
4. On your graph, you will see that the angular velocity of the system drops suddenly with the increase in mass. The angular velocity just before this decrease is ω_0. The angular velocity just after this is ω_f. Perform this experiment 4 times.
5. Once you have your data, compare the total amount of momentum that the systems had before and after the "collision". That means you will need to calculate the total angular momentum before and after the collision.

Questions Part 3:

1. Did the experiment show that angular momentum, like linear momentum, is conserved? Does your data show this?
2. How does the friction of the bearings in this experiment affect the data? Does the friction in the bearings of the device apply a torque on the system?
3. In each of the experiments you either dropped or removed a mass from the system. What type of collision was this: elastic or inelastic?

The Moment Of Inertia for Various Geometries Objects

	Object	Location of axis		Moment of inertia
(a)	**Thin hoop,** radius R	Through center		MR^2
(b)	**Thin hoop,** radius R width w	Through central diameter		$\frac{1}{2}MR^2 + \frac{1}{12}Mw^2$
(c)	**Solid cylinder,** radius R	Through center		$\frac{1}{2}MR^2$
(d)	**Hollow cylinder,** inner radius R_1 outer radius R_2	Through center		$\frac{1}{2}M(R_1^2 + R_2^2)$
(e)	**Uniform sphere,** radius R	Through center		$\frac{2}{5}MR^2$
(f)	**Long uniform rod,** length ℓ	Through center		$\frac{1}{12}M\ell^2$
(g)	**Long uniform rod,** length ℓ	Through end		$\frac{1}{3}M\ell^2$
(h)	**Rectangular thin plate,** length ℓ, width w	Through center		$\frac{1}{12}M(\ell^2 + w^2)$