

PHYS 1401 – General Physics 1  
Laboratory # 7  
Rotational Motion

**Part 1: Angular Acceleration**

As discussed in class, if we want to measure how fast an object is spinning, we use a quantity called angular velocity, represented by the Greek letter omega ( $\omega$ ). Angular velocity is the rate of an object's spin. If that rate of spin is changing, spinning faster or slower, that change is called an angular acceleration. The symbol for angular acceleration is the Greek letter alpha ( $\alpha$ ), and it is calculated from the formula

$$\alpha = \Delta\omega / \Delta t = (\omega_f - \omega_0) / (t_f - t_0)$$

In this experiment we will calculate the angular acceleration of a wheel attached to a falling weight. Notice that the wheel apparatus has three smaller wheels stacked at the center. These smaller wheels are where we will attach the string that will pull the apparatus as a whole. The string runs over a pulley and is attached to a hanging mass. As the mass falls, the wheel will turn. Note the small black wheel that is in contact with the larger gray wheel. This black wheel will turn with the gray wheel, and the computer will translate the black wheel's motion into the gray wheel's motion. The computer will tell us the angular velocity of the large wheel at various times, and we will use this information to calculate the angular acceleration of the wheel.

Wind the string around the largest of the small aluminum wheels on top of the larger wheel. Attach the other end of the string to the mass holder, and place a 50-gram mass on the holder. With the holder's mass of 5 grams, this makes a total of 55 grams on one end of the string. Place the string over the pulley and let the mass hang. Adjust the height of the pulley so that the string is parallel to the table. Hold the hanging mass as high up as you can.

Click on the "Collect" button and release the hanging mass. The mass will fall, the wheels will spin, and numbers will appear on the screen. There is a bit of a delay for data to appear on the screen, so data will appear even after the weight hits the floor. Wait for at least 60 data points to appear, and then click the "Stop" button.

Note that you are given time information and angular velocity information for each data point. Ignore the "DeltaT" data in the middle, as it is irrelevant to our work. Record the time and angular velocity data for the 10<sup>th</sup> data point, for the 20<sup>th</sup> data point, and for every 10<sup>th</sup> data point thereafter, until you have six sets of data points in a data table.

Note that in addition to numerical data, the computer produces a graph of angular velocity versus time. The graph should be a straight line, showing that angular acceleration gradually increases over time. The slope of that line is the angular

acceleration – the steeper the line, the greater the acceleration. Make a mental note of how steep the line appears.

One person in the lab group can then begin to calculate angular accelerations while the other(s) continue gathering data. The procedure for calculating angular accelerations is as follows: start with the 1<sup>st</sup> set of time and angular velocity information as  $t_0$  and  $\omega_0$  and the 2<sup>nd</sup> set as  $t_f$  and  $\omega_f$ . Use the formula on the first page to calculate a value for the angular acceleration for that pair of data points. Then make the 2<sup>nd</sup> set of data points  $t_0$  and  $\omega_0$  and the 3<sup>rd</sup> set of points  $t_f$  and  $\omega_f$  and calculate another value. Continue this until you have used all the data and have five values for the angular acceleration. Record all five values for  $\Delta\omega$ ,  $\Delta t$ , and  $\alpha$ , as well as the average angular acceleration, in a data table labeled “55 grams, largest wheel.”

Carefully rewind the string around the largest of the small wheels on top of the large wheel. Repeat your measurements and calculations for hanging masses of 35 grams and 75 grams. Record all your results in appropriately labeled data tables. Compare the steepness of the graphs to the 55-gram results.

**Question 1: Does changing the size of the hanging mass change the wheel’s acceleration? If so, in what way? Back up your assertions with data.**

**Question 2: What force is causing the wheel to spin? This motivating force should be approximately equal to what other force? How can this explain your answer to Question 1?**

Carefully wind the string around the smallest of the small wheels. You may have to adjust the height of the pulley to keep the string parallel with the table. Repeat your observations and calculations for 55 and 75 grams.

**Question 3: Does changing to the smaller wheel change the angular acceleration? If so, in what way?**

Write up preliminary answers to these three questions to submit at the beginning of the next class. You will submit your final answers with the lab report as well.

## **Part 2: Torque and Moment of Inertia**

In Part 1, we discovered that applying different forces to different parts of the wheel changed the angular acceleration of the wheel. The string applies a force to the wheel, and this force generates a torque, which in turn causes an angular acceleration. The greater the force applied, the greater the torque. The closer the force is to the center of the wheel, the less torque is generated. A third factor, which we did not include in our experiment last time, is the angle  $\phi$  at which the force is applied. This is the angle between the force vector distance from the center of the wheel to the point where the force is applied.

Therefore, the formula for torque is

$$\text{Torque } \tau = (\text{Force})(\text{Distance from center})(\sin \phi)$$

**Question 4: What is the angle  $\phi$  for our apparatus? Remember, the tension force acts along the string. Write out a working equation for torque based on this value.**

Just like unbalanced forces cause accelerations, unbalanced torques cause angular accelerations. We can create a version of Newton's Second Law for rotational motion:

$$\Sigma \tau = I \alpha$$

Where  $\alpha$  is the angular acceleration and  $I$  is a quantity called moment of inertia. Moment of inertia is the rotational equivalent of mass – it is a measure of how hard it is to make something spin, or stop it from spinning. Moment of inertia depends on the mass of the spinning object, its radius, and how the mass is distributed – its shape. In this part of the experiment, we will experimentally determine the moment of inertia for two objects.

Combining the two equations above gives us

$$(\text{Force})(\text{Distance})(\sin \phi) = I \alpha$$

**Question 5: If the string is wrapped around the middle of the three small wheels, what will the value of the distance be? Hint: It is NOT the radius of the large gray wheel!**

Carefully wind the string around the middle of the three wheels. Place 30 grams on the holder (for a total of 35 grams) and place the string over the pulley. Remember to adjust the height of the pulley to insure that the string is parallel to the table. As in part 1, hit the "Collect" button and let the mass fall. Gather data as you did in Part 1 to find the average angular acceleration. Combine this with information on the force, distance from the center, and angle to find the moment of inertia of the gray disk.

Repeat the experiment for total masses of 55 and 75 grams. Compile your results in a data table with entries for force, distance from the center, average angular acceleration, and moment of inertia. Average the three values of  $I$  to get a "measured" value for moment of inertia.

We are spinning what is essentially a solid disk. Look up the formula for the moment of inertia of a solid disk in the textbook. Measure whatever you need to know to compute the moment of inertia of the disk. Record this as your "computed" value for moment of inertia. Find and record the percentage difference between the two values for moment of inertia using the formula

$$\text{Percentage Difference} = 100\% \times \frac{(\text{Measured} - \text{Calculated})}{\text{Calculated}}$$

**Question 6: Technically, the gray disk is not a true solid disk because of the three smaller wheels attached to it. Do the smaller wheels make a significant difference in the actual measured value for moment of inertia compared to the theoretical value assuming a uniform disk? Remember, with our instruments we can expect uncertainties of about 10%.**

BONUS:

You are also provided with a black ring, which can be placed on top of the disk. The total moment of inertia of the system is now

$$I_{\text{tot}} = I_{\text{disk}} + I_{\text{ring}}$$

**Question 7: Describe in a few sentences the procedure you would use to measure the moment of inertia of the black ring.**

Determine the measured value of the moment of inertia for the black ring. You only need to use one mass. Calculate a theoretical value for the moment of inertia, using the formula for an “annular cylinder” in the text, and a percentage difference as before. Summarize your results in a data table similar in structure to the one for the gray disk alone.