Physics 120 Lab 8: Moment of Inertia using the Energy Principle

Name: ___________________ Partner: ___________________ Date: _______

Introduction

In this experiment you will determine the rotational inertia of a body by applying the Energy Principle to a rotating turntable. Recall from class that the rotational inertia, $I$, of a body is a measure of the body’s tendency to resist a change in its state of rotational motion and that the rotational kinetic energy is given by

$$K_{rot} = \frac{1}{2} I \omega^2,$$

where $\omega$ is the angular speed.

The experimental setup is shown in the figure below. The apparatus consists of a hanging mass, $m$, connected by a string passing over a smart pulley to the spool of a rotator (which includes a large disk). The string is wrapped around the spool and the mass is allowed to fall. Due to the torque by the tension in the string wrapped around the spool, the rotator will then rotate. The smart pulley is connected to the DataStudio system and will measure the speed of the falling mass as a function of time. We will then apply the energy principle to this motion.
1. List all the components of the total mechanical energy, \( E_T \), of the system, where the system is composed of the rotator apparatus (including the large disk), the string, the hanging mass, and the Earth. Note that this is a closed system. Assume no energy dissipation due to friction, and neglect the kinetic energy in the string and smart pulley wheel.

2. Write an expression for the total kinetic energy of the system.

3. Write an expression for the angular speed of the rotator, \( \omega \), in terms of the radius of the spool, \( r \), and the speed of the hanging mass, \( v \). Note that the speed of the hanging mass must equal the speed of the string, which equals the tangential speed of the edge of the spool.

4. Into your expression from step 2, substitute in for the angular speed \( \omega \) using your expression in step 3.

5. Write an expression for the change in potential energy of the system.

6. In the experiment, the entire system will start from rest and the mass will fall a height \( \Delta y \) and obtain a final speed \( v_f \). Write an equation to apply the conservation of energy of this closed system. Your equation should involve the variables \( m \), \( I \), \( r \), \( \Delta y \), and \( v_f \).
7. Algebraically manipulate this equation to get an expression for the rotational inertia, \(I\), of the rotating system in terms of all the other variables. Check with your instructor before continuing.

**Data Collection**

1. Open Excel. At the top, input the names of both partners or all members in the group.

2. Use the vernier caliper to measure the diameter of the rotator spool (the part of the rotator that the string wraps around). Calculate the radius, \(r\), of the spool and record (with the appropriate uncertainty) in the Excel table in a cell at the top. In a neighboring cell, label this as \(r_{spool}\). Don’t forget to list the unit. If you have questions about how to read the vernier, consult your instructor.

3. In the next row of the Excel table, input the following column headers:

| \(m_{\text{hanging}}\) | \(\Delta y_{\text{disk only}}\) | \(v_{\text{disk only}}\) | \(I_{\text{disk only}}\) | \(\Delta y_{\text{disk+cyl}}\) | \(v_{\text{disk+cyl}}\) | \(I_{\text{disk+cyl}}\) | \(I_{\text{cylinder}}\) |

List appropriate units in the next row.

4. Open *DataStudio* by clicking on the icon of a pencil and paper (and labeled “English” when the cursor scrolls over it) in the programs bar at the bottom of the screen. Click “Open Activity,” browse to the desktop and select “rotational inertia.”

5. Make sure that the black hollow cylinder is NOT on the rotating system to start.

6. Hang a 0.100 kg mass from the string and make sure that the string passes over the pulley and that the smart pulley is at the right height so that the string winding around the spool is horizontal.

7. Turn the rotator to wind the string around the spool until the mass is about a centimeter from the pulley.

8. Click “Start” in *DataStudio* and release the rotator. Click “Stop” before the mass hits the ground. *Also, be sure to stop and catch the wheel before the mass hits the ground* to prevent the string from winding around the other side of the spool.

9. From the graphs, using the smart cursor, obtain the final velocity and change in height of the falling mass. Make sure that your final velocity matches up in time with your final position. Record these values in the data table on the attached page.

10. Repeat steps 5-8 for hanging masses of 0.2, 0.3 and 0.5 kg. Only if time allows, also do 0.050 kg.
11. Add the hollow cylinder to the rotating system and repeat steps 5-9.

12. Measure and record in the Excel table, the mass, $M_{cyl}$, the inner radius, $R_1$, and the outer radius, $R_2$, of the cylinder. Be sure to label these cells in the table. Also, include estimates of the uncertainties.

**Analysis**

1. Use the equation from step 7 in the Introduction to calculate the rotational inertia of the rotating system for each trial.

2. In Excel, subtract $I_{disk\ only}$ from $I_{disk+cyl}$ to get $I_{cyl}$ for each value of $m_{\text{hanging}}$.

3. Calculate the average and standard error for $I_{cyl}$. Label these cells, and make the entries bold-faced. Copy your answers in the space below as well.

   $I_{cyl} =$

4. The rotational inertia of the hollow cylinder should be given by $I = \frac{1}{2} M_{cyl} (R_1^2 + R_2^2)$. Using the measurements of $M_{cyl}$, $R_1$, and $R_2$ calculate the theoretical rotational inertia of the cylinder. Write your answer in the following space.

5. Calculate the uncertainty in the theoretical moment of inertia by propagating the uncertainties. Hints: $\frac{\partial I}{\partial M} = I/M$, and $\frac{\partial I}{\partial R_1} = MR_1$.

6. Do the experimental and theoretical values for the moment of inertia agree to within the uncertainties?

7. Email your Excel file to your instructor (one per group) and turn in this packet (one per student).