**Experiment**

**9**

Rotational Inertia

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**Introduction**

The purpose of this lab is to experimentally measure the rotational inertia of a ring, a disk rotating about its center of mass, and a disk rotating about its diameter and compare each measured value to their corresponding theoretical value.

**NOTE: You will need to upload the Capstone file of your collected data into Canvas to get credit for the lab report (no emailed files accepted). The data in the Capstone file must match the data in your report. You will need to include one sample graph for each part of the lab.**

**Theory**

1. **Geometrical:** The rotational inertia of an object depends on its mass and how that mass is distributed about the axis of rotation. In this section you need to derive the expressions for the rotational inertia of the three systems to be tested in this experiment starting with the definitions:

Let each system have mass M. The disk has radius R and the ring radii R1 and R2. Use the above equation to derive the expressions for the moments of inertia of a ring of radii R1 and R2 and mass M about its center of mass, a disk of radius R and mass M about its center of mass, and a disk of radius R and mass M about its diameter.

**I =**

1. **Experimental:** To measure the rotational inertia of our systems we will use the apparatus shown on the following page. Using free-body analysis and Newton’s 2nd Law for rotating systems derive the expression for the experimental value of the rotational inertia

T

Mg

M

Your final expression should involve only quantities that you have measured, or well-known numerical constants.

**Apparatus**

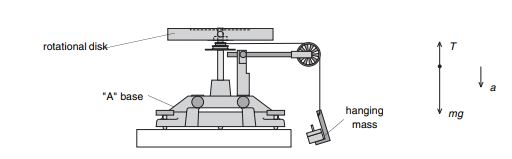
- Capstone Program -Mass and Hanger Set

- PASCO Interface - Paper Clips (for masses < 1 g)

- Rotational Inertia Accessory (ME-8953) - Balance

- Photogate/Pulley System - Calipers

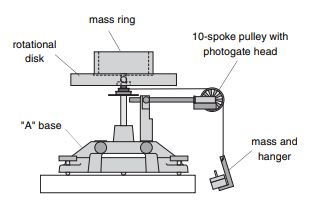
- Rotating Platform System (ME-8951)



**Figure 1 Free-body diagram for hanging mass in Ring-Disk System.**

**Procedure**

1. Weigh the ring and disk to determine their masses and record their values in Table 1 in the Data section.



**Figure 2 Setup for Disk and Ring**

1. Measure the inside and outside diameters of the ring and calculate the radii R1 and R2. Record in Table 1.
2. Measure the diameter of the disk and calculate the radius R and record it in Table 1.
3. Setup the system as shown on the right. Make sure the ring is seated in the indentation of the disk.
4. Open the Capstone file titled *Moment of Inertia Large.cap*.

**Accounting for Friction within the System**

Because the theory used to find the rotational inertia experimentally does not include friction, it will be compensated for in this experiment by finding out how much mass over the pulley it takes to overcome kinetic friction and allow the mass to drop at a constant speed. Then this “friction mass, **mf**” will be subtracted from the mass used to accelerate the apparatus.

1. Hang a small amount of mass such as a mass hanger or a few paper clips or small lab masses on the end of the thread that is over the pulley.
2. Wrap the thread around the largest of the three-step pulley below the disk. Give the Rotational Disk a tap to get it started moving and observe the velocity vs. time graph.
3. If the velocity increases or decreases as the Rotational Disk turns, stop monitoring data, stop the Rotational Disk, and adjust the amount of mass on the thread by adding or removing a paper clip.
4. Repeat the process until the velocity stays constant*.*
5. Measure the mass on the end of the thread and record it as the Friction Mass **mf** in Table 2. Don’t forget to estimate its uncertainty. This value will be higher than the uncertainty in the scale why. Why?
   1. Because we aren’t accounting for the hanger.
6. Repeat steps 1 through 5 with for the disk alone rotating about its center of mass and then with the disk rotating about its diameter. Record the results in Table 2. It is expected that the friction mass will not change very much.

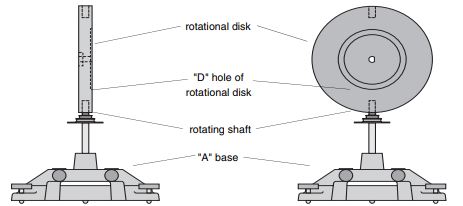
**Measuring the Acceleration of the Ring and the Disk**

1. Measure the largest diameter of the 3-step pulley. Measure largest diameter of the 3-step pulley with the string wrapped around it. Make sure the string is attached to the correct pulley. Compute the average pulley radius along with its estimated uncertainty. Records the results below Table 2.
2. Reset the ring on the disk as as shown in Figure 2. Make sure the ring is seated in the indentation of the disk.
3. Place 45-50g on the hanger. Measure and record this the total hanging mass in Table 2.
4. Wrap the thread around the largest of the three-step pulley below the disk. Press **Record** and release the hanging mass at the same time. Press **Stop** just before the mass hits the floor.
5. Observe the Velocity vs. Time graph. The slope of the linear fit yields the linear acceleration of the falling mass. Record its value along with its uncertainty in Table 2.

***Caution:*** *To report the measured acceleration in a manner that is consistent with its uncertainty, you might need to modify the display of the fitting parameter for each run. To change the display of the fitting parameters, follow the instruction below:*

* *Click the curve fit display box, right click within this box, and select “Curve Fitting Properties.”*
* *Choose “Numerical Format.”*
* *Click the upside-down triangle next to “Coefficients” and select “Fixed Decimal” from the drop-down menu next to “Number Style.”*
* *Choose a number greater than 4 from the drop-down menu “Number of Decimal Places” and click the upside-down triangle next to “Coefficients.”*
* *Click the upside-down triangle next to “Coefficient Uncertainties” and select “Fixed Decimal” from the drop-down menu next to “Number Style.”*
* *Choose a number greater than 4 in the drop-down menu “Number of Decimal Places” and click the upside-down triangle next to “Coefficient Uncertainties.”*

1. Repeat steps 3 and 5 one more time to check for consistency.
2. Since the disk is rotating as well as the ring in steps 2-4, it is necessary to determine the acceleration, and the rotational inertia, of the disk by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the ring. Remove the ring and place 25g-50g on the hanger. Measure and record this the total hanging mass and record the results in Table 2.
3. Repeat steps 4-6.
4. Remove the disk and reduce the hanging mass (just leave the mass hanger on), repeat steps 4-6. Record the data in Table 2. This will allow you to determine the effective moment of inertia of the apparatus.



**Figure 3-Vertical disk setup.**

1. Remove the disk from the shaft and rotate it up on its side. Mount the disk vertically by inserting the shaft in one of the two “D”-shaped holes on the edge of the disk. See Figure 3.
2. Place 25g-50g on the hanger. Measure and record this the total hanging mass and record the results in Table 2.
3. Repeat steps 4-6.

**Data**

## Table 1- Geometrical Data (include uncertainties)

|  |  |
| --- | --- |
| **Mass of Ring (g)** | 1439.47 |
| **Mass of Disk (g)** | 1481.68 |
| **Inner Diameter of Ring (vernier cm)** | 10.686 |
| **Outer Diameter of Ring (vernier cm)** | 12.740 |
| **Inner Radius of Ring, R1 (cm)** | 5.343 |
| **Outer Radius of Ring, R2(cm)** | 6.370 |
| **Diameter of Disk**  **(ruler cm)** | 22.96 |
| **Radius of Disk, R**  **(ruler cm)** | 11.48 |

# Table 2- Experimental Data (include uncertainties)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Friction Mass, mf (g)** | **Hanging Mass, mH (g)** | **Net Hanging Mass, m (g)** | **Acceleration**  **(m/s)** |
| **Ring and Disk** | 6.02 | 45.15 | 39.13 | .0109 |
| **Disk Alone** | 5.0 | 45.15 | 40.15 | .173 |
| **Vertical Disk** | 4 | 45.15 | 41.15 | .299 |
| **Apparatus Alone** | 0.5 | 0.5 | .5 | .828 |

**Dp (without string wrapping) \_\_\_\_\_\_\_3.740cm\_\_\_\_\_\_\_\_**

**Dp (with string wrapping) \_\_\_\_\_\_3.756cm\_\_\_\_\_\_\_\_\_**

**Dpavg (with uncertainty) 3.748 cm**

**Analysis and Results**

1. Use the data you recorded in Table 2 and the equation you derived in the Theory section and follow the steps below to calculate the experimental value of rotational inertia of the Ring and the Disk. Note that the quantity ***m*** in the equation derived in the Theory section is the hanging mass minus the friction mass.
2. Calculate the experimental value of the rotational inertia of the ring, disk, and apparatus.
3. Calculate the experimental value of the rotational inertia of the disk and apparatus.
4. Calculate the experimental value of the rotational inertia of the apparatus itself.
5. Subtract the rotational inertia of the disk and apparatus from the total rotational inertia of the ring, disk, and apparatus. This will be the rotational inertia of the ring alone.
6. Subtract the rotational inertia of the apparatus from the total rotational inertia of the disk and apparatus. This will be the rotational inertia of the disk alone.
7. Use the propagation of error equation to propagate uncertainty in linear acceleration, hanging mass, friction mass, and radius of pulley to derive a general expression for the uncertainty dIexp in Iexp.
8. Use the above expression to calculate dIexp for the disk, ring, and apparatus (the uncertainty in the value of part a) combined.
9. Use the previous results to calculate dIexp (the uncertainty in the value of part a minus the value in part b) for the ring. *Note: Don’t forget there is a subtraction.*
10. Use the previous results to calculate dIexp (the uncertainty in the value of part b minus the value in part c) for the disk. *Note: Don’t forget there is a subtraction.*
11. Calculate the experimental value of the rotational inertia of the vertical disk and apparatus.
12. Subtract the rotational inertia of the apparatus from the total rotational inertia of the vertical disk and apparatus. This will be the rotational inertia of the vertical disk alone.
13. Use the previous results to calculate dIexp (the uncertainty in the value of part b minus the value in part c) for the vertical disk. *Note: Don’t forget there is a subtraction.*

1. Calculate the geometric values of the rotational inertia of
2. of the ring.

**)**

1. of the disk rotating about its center of mass.
2. of the disk rotating about its diameter.
3. Use error propagation to determine the uncertainty in the geometrical value of the rotational inertia of the ring.
4. Use error propagation to determine the uncertainty in the geometrical value of the rotational inertia of the disk rotating about its center of mass.
5. Use error propagation to determine the uncertainty in the geometrical value of the rotational inertia of the disk rotating about its diameter.

**Results (all results must be expressed in SI units)**

Ring: I (Experimental) = \_\_.0043\_\_\_\_\_\_\_±\_\_\_.0001\_\_\_\_\_\_

I (Theoretical) = \_\_**\_**\_\_\_\_\_\_±\_\_\_ *.000002* \_\_\_\_\_\_

% Difference = \_\_\_\_12\_\_\_\_\_\_\_\_\_\_\_

Disk: I (Experimental) = \_\_\_\_.00797\_\_\_\_\_±\_\_\_\_.00009\_\_\_\_

I (Theoretical) = \_\_\_.009767\_\_\_\_\_\_±\_\_\_\_\_\_\_\_\_

% Difference = \_\_\_20\_\_\_\_\_\_\_\_\_\_\_\_

Vertical Disk: I (Experimental) = \_\_\_.00472\_\_\_\_\_\_±\_\_.00005\_\_\_\_\_\_\_

I (Theoretical) = \_\_.0048478\_\_\_\_\_\_\_±\_\_.0000009\_\_\_\_\_\_\_

% Difference = \_\_\_\_\_2.62\_\_\_\_\_\_\_\_\_\_

**Please write a formal conclusion to this experiment. Include the sources of error in the experiment and the size of** δI**. Comment on whether geometric and experimental values agree, the largest contributor to the error and suggest ways to improve the experiment by eliminating, minimizing, or compensating for this source.**

The purpose of this lab was to verify the connection between the measured moment of inertia values and the geometrical expected values (mathematical) values that we are expected to receive without testing or experimentation. Throughout this lab our group gathered data, derived formulas, and synthesized experimental information for further analysis.

After synthesis of data, we compared that data to our geometrical data that we calculated for using mathematics alone. Our greatest difference in experimental and geometrical data found a 20% difference in result, while our most accurate difference was found by the vertical disk with a difference of just 2.62%. We are confident that this data reasonably verifies the connection between the geometrical and experimental data gathering methods. However, due to the fact the uncertainty values do not overlap, we assert there must have been systematic error present within the experiment.

In this experiment we found the greatest source of error to be that the disk we used throughout the experiment is not a perfect disk. The disk has grooves in it. Portions of the disk are missing which could explain the lack of overlap within our values.

To eliminate the primary source of error we must find a disk that compensates for the lost mass within the grooves of the disk by distributing the mass unevenly throughout the disk.