M22a: Rotational Dynamics & Determining the Moment of Inertia

Introduction:

The goal of this experiment is to determine the moment of inertia of a rotating body by measuring the torque acting upon the body and the corresponding angular acceleration produced by the torque, a concept explained further within the **Discussion** section. The experimental moment of inertia will then be compared to a theoretical determination of its moment of inertia.

The apparatus used in this experiment consists of a massive wheel mounted on an axle that can rotate freely in pivot bearings. The disk is set in motion by means of a weight attached to a string, which is wound around the axle. As the weight descends it will move with a constant linear acceleration. The angular acceleration of the wheel and axle depends on the applied torque, the frictional torque, and the moment of inertia. Assuming the last two remain constant during the experiment, the angular acceleration can be varied by changing the applied torque. Once multiple trials are conducted with different applied torques and their corresponding angular accelerations it is possible to compute the moment of inertia and the frictional torque from the observations taken.

The value of the moment of inertia obtained experimentally can be checked by modeling the apparatus as a combination of three cylinders. Measurement of the dimensions of the wheel and the axle together with the mass can be used to separately calculate the moment of inertia for each of the cylinders. The sum of the three is equal to the total moment of inertia for the combination.

Apparatus:

- Wheel and axle apparatus
- Digital calipers
- Masses
- Light mass hanger
- Heavy mass hanger
- String
- Computer timing system

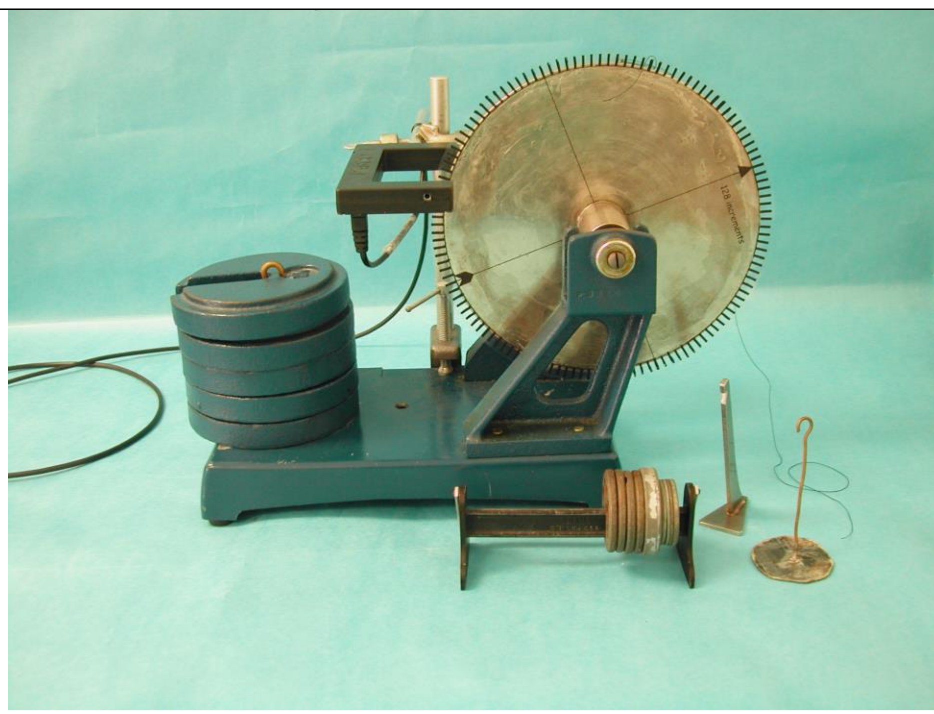

Figure 1

Discussion:

The dynamical behavior of rotation has analogous components to the behavior of translational motion. Torque replaces force, angular acceleration replaces linear acceleration and moment of inertia replaces mass. The moment of inertia of a body describes not only how much matter a body is composed of, but also how that matter is distributed about the axis of rotation. This experiment examines some of the properties associated with these components of rotation. When a rigid body is acted upon by a system of torques, where the sum of these torques is zero, the rigid body is in equilibrium with respect to rotation. This means that the body can only have two rotational motion states: to be at rest or to rotate uniformly about a fixed axis. If the sum of the system of torques is not equal to zero but is equal to some net torque, then the rigid body will experience an angular acceleration in the direction of the net torque. This behavior is described in Newton's second law for rotation:

$$\tau_{net} = I \times \alpha$$

τ_{net}	is the net torque of the system of torques about the axis of rotation
I	is the moment of inertia of the body about the same axis
α	is the angular acceleration

For a complete discussion on this topic with the details necessary for many of the calculations, read the chapter in your textbook on Rotation. Also, several of the prior experiments conducted have covered most of the intermediate equations needed in this experiment.

Halliday Resnick Walker. Fundamentals of Physics, chapter 10

Young & Freedman. Sears and Zemansky's University Physics, chapter 9

Procedure:

1. Identify the apparatus components (wheel, right axle, left axle) then use a caliper to measure the following:
2. Measure the diameter of the axle (the left and right axle have the same diameter); obtain and record the radius of the axle.
3. Measure and record the length of the right axle and the length of the left axle.
4. Measure and record the length of the wheel (it is the thickness of the wheel).
5. Measure the distance ***d*** from the edge of the wheel to the axle; obtain the radius of the wheel by adding ***d*** and the radius of the axle, and record it.
6. Read the total mass from the side of the wheel.
7. Before proceeding to the actual experiment, it is necessary to perform the theoretical calculations. Calculate each individual volume of the wheel, right axle, and left axle (Hint: all the objects are cylinders).
8. Obtain the volume of the system by adding the three individual volumes.
9. Calculate the density of the system, using the total mass dividing by the volume of the system.
10. Calculate the individual masses of the wheel, right axle, and left axle by using the density of the system multiplying each corresponding individual volume.
11. Calculate the individual moments of inertia ***I*** of the wheel, right axle, and left axle.
12. Calculate the total ***I*** by adding the three individual ***I***s. **Please check with the lab instructor to confirm that the proper total moment of inertia has been calculated before proceeding to the actual experiment.**
13. Once the moment of inertia has been confirmed as correct; log in to the computer and open the appropriate data collection program for the experiment M22a.
14. Wrap the string around the wheel.
15. Pick up the light hanger and the 20g mass; put the mass on the hanger and measure its total mass. Record it in the first cell under the column of "applied mass."
16. Attach the hanger (with the 20g mass) to the string, and hold the string; make sure the hanger is suspended in the air without touching the table.
17. Follow the provided computer instructions for data collection.
18. Start the computer data collection, release the mass allowing it to move toward the floor and stop the computer data collection once the mass reaches the floor.
19. The computer will display a graph of angular velocity as a function of time. The statistical slope of the line provides the angular acceleration.
20. Record the value of the slope shown on the box under the column of "angular acceleration." Record the standard deviation of the acceleration.
21. Calculate the linear acceleration, tension, and torque.
22. Repeat steps 14 through 21 for 4 trials, each time adding another 10g mass to the hanger.
23. Wrap the string around the axle and repeat the above steps using the heavy hanger instead of the light hanger; start with the 100g mass. Increase the mass by 50g for each additional trial.
24. Final step: Graph the torque as a function of the angular acceleration using all ten data points**.** The slope of the linear regression line will be the experimental moment of inertia.

Experiment M22a: Moment of Inertia

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: M22a: Moment of Inertia

NAME: ______________________________ **DATE:** __________________

total Mass of system	
diameter of axle	radius of axle
length of left axle	
length of right axle	
distance wheel to axle	radius wheel
length of wheel	

		wheel	right axle	left axle
theoretical	individual volume			
	volume of system			
	density of system			
	individual mass			
	individual: $I = \frac{1}{2}mr^2$			
	total I			

Data Sheets: M22a: Moment of Inertia

NAME: ______________________________   DATE: __________________

	applied mass	(α) ang. acc	std. dev.	linear acc.	tension	(τ) torque
wheel						

	applied mass	(α) ang. acc	std. dev.	linear acc.	tension	(τ) torque
axle						

moment of Inertia: $I_{\text{exp}} = \left(\dfrac{\tau}{\alpha}\right)$ ______________________________

regression slope