EXPERIMENT 9: ROTATIONAL KINEMATICS AND INERTIA

To study rotational motion experimentally we need to be able to calculate or measure ω and α for rotating objects. The "Rotational Dynamics Apparatus" allows us to do this. The metal discs have alternating light and dark strips 1.0 mm wide around their circumference. When these strips pass a photocell, they are counted, and angular position, velocity and acceleration may be calculated.

BACKGROUND

In order to calculate rotational inertia we want a method to minimize the effect of friction. This is the purpose of the "Rotational Dynamics Apparatus", which provides for metal disks to float on a cushion of air from a compressed air tank in the next room. When the output of the apparatus is connected to a computer, the computer can collect and store the information and print a table or graph for later use, or give output on the screen to be copied. The program can also do some calculations for us, such as slopes and averages.

If we know the angular acceleration, we can use Newton's second law for rotational dynamics to calculate the rotational inertia, I. If you have not already done so, you should read chapter 10, section 6 & 7 to review the concept of rotational inertia. Table 10-2 gives the rotational inertia of some objects, including the disk and rectangular object you are using in this experiment. Sample problem 10-8 shows how Newton's second law is used to calculate α, the angular acceleration, when we know I. The formula below is the result of applying the same analysis, but using the known α (from the computer collected data) to calculate I.

$$\mathrm{I} = r^2\, m\left(\frac{g}{r\alpha} - 1\right)$$

ADVANCE STUDY ASSIGNMENT

1. Derive the formula above which will be used to calculate the experimental rotational inertial. Use dynamics and include free body (or extended body) diagrams for the rotational part and the falling body part.
2. Note that there are two values of acceleration on the Data Table, one for mass falling and one for mass rising. Should these two accelerations be the same? Consider two cases: the ideal case of no friction and the real case of some small amount of friction always present.

PROCEDURE A

1. If the computer is not already set up, turn on the interface first, then turn on the computer. The yellow-banded plug should be plugged into digital channel one and the other plug into digital channel two. Open Data Studio, go to the sensor box and

scroll down to Rotational Dynamics Apparatus, double-click on the icon for this sensor. On Data window, drag each of the three items in turn to the graph icon on the Display Window (to display a graph; drag second and third items to Graph 1.)

2. Now turn the air supply on, to 9 psi (pounds per square inch), by turning the yellow knob clockwise, while pulling up lightly. (Pushing down will lock the knob and you will be unable to turn it.)
3. Wind the string around the pulley by rotating the flat disk on the apparatus with your hand. The 25 g weight will be pulled up. Continue winding until the weight is near the top.
4. When the weight is near the top, hold the disk still, then click on "Start" to record data, and release the disk. Allow the weight to fall down, and be ready to click "Stop", and at the same time turn the air supply off when the weight rises back to the maximum height. Turn the air off by turning the yellow valve counter-clockwise, while pulling up lightly. Graphs of the three angular variables, position, velocity and acceleration vs time should be displayed.
5. If necessary, click on the auto scale button, shown at the top left of the graph window. This automatically adjusts the scale so the curve of the graph fills the space available. If the graphs look reasonable, save them to a floppy disk by clicking on the "File" button on the menu bar, then moving down to "Save activity as…". Put a name in the file name box, such as "yourname" and then change to the "a drive" by using the arrow in the box labeled "drives" in the top of the Save window. Finally, click ok.
6. Now go to another computer. Start the computer (without turning on the interface), and choose "Open Activity" at the prompt after double clicking on Data Studio. Insert the floppy in the drive, and open the file you saved by going to the File drive on the menu bar, remembering to change to "a" drive.
7. Study the three graphs and note the relationship between position, velocity and acceleration. Note the distinct parts of each graph, how they correlate to each other and to the parts of the experiment (weight falling, weight rising, delay after turning air off but before clicking stop button, if any). Decide which part of the graphs corresponds to the weight falling.
8. It is best to work with the parts of the graph corresponding to the falling weight portion. Click autoscale again, if the graphs do not fill the entire space. With the mouse, click on a portion of the graph you want to use on the position vs time graph and draw a rectangle around the section of data you want to use, by holding the mouse button down while you move to the opposite corner of the rectangle. There may be a small delay in the rectangle being drawn after you click and move the mouse.
9. Now click "Fit" on the graph window menu bar, and then select "Polynomial Fit". Make sure the fit curve is matching only the part you highlighted. (You may need to double click on the polynomial box which appears on the graph to make sure there are only A, B and C coefficients given. Record the coefficient of the x^2 term (the C coefficient) on the Data Table.
10. Repeat the last procedure with the velocity graph, using the same time range as in procedure 9, but this time select "Linear Fit" and record slope.
11. Repeat the last procedure again on the acceleration graph, with the same range of time as in the last two procedures. Now click on the Σ button, and select "Mean".

The average acceleration for the data enclosed by the rectangle you drew should be displayed. Again, record the value for later use.

12. Now select the area of the acceleration graph that matches the weight rising, and find the average acceleration for that interval, and record on the data table.
13. Next use the equation in the Background section to calculate the rotational inertia of the disk. You will need to convert a to rad/s^2, using the average of the three values for the falling portion of graphs. This will be your experimental value of rotational inertia.
14. While other students are using the apparatus, measure the diameter of the alternate disk, which is the same as the one you are using. Also measure the mass, length and width of the black rectangular solid and the diameter of large pulley, which will be used in Procedure B. Record all these values in the data table.

PROCEDURE B

15. We will now repeat the whole process (Procedure steps 2 through 12) to calculate the experimental rotational inertia of a solid rectangular object, by placing it on top of the disk we just used. We then calculate $I_{combination}$ as before, and then $I_{bar} = I_{combination} - I_{disc}$. Again, record all data on the data table in the spaces provided.
16. Use the theoretical expressions of I_{disk} and I_{bar} from Table 11-2 in the textbook, and compare I_{theory} with I_{exp} for the 2 cases.

QUESTIONS

Answer the first three questions for the 3 graphs, x, v and a vs t.

1. What does the shape of the position graph curve look like? How good is the fit?
2. What does the shape of the velocity graph curve look like? How good is the fit?
3. What is the relation between a_3, a_2, and a? Show the relationship by using equation of kinematics for angular motion.
4. Are the values of acceleration for the rising and falling areas of the graph the same or different? What does this indicate?

DATA TABLE A and **B**

$r_{\text{small pulley}}$ ______________ m_{falling} ________________

DISK			COMBINATION	
M	____________		M	____________
D	____________	BAR 	L	____________
R	____________		w	____________
a_3	____________	From position graph	a_3	____________
a_2	____________	From velocity graph	a_2	____________
a	____________	From acceleration graph, falling	a	____________
a	____________	From acceleration graph, rising	a	____________

$I_{\text{COMBINATION}}$ ________________

DISC		BAR
________________	I_{Theory}	________________
________________	I_{exp}	________________