Rotational Dynamics

Purpose:

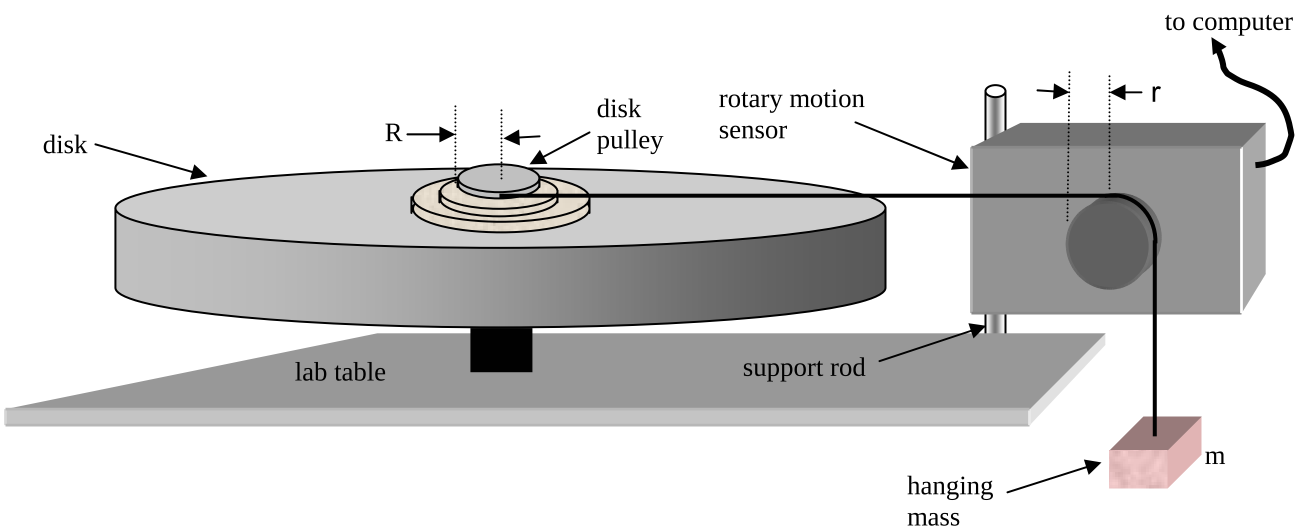
1. To study and measure the effect that torques have on the rotational motion of a disk.
2. To gain experience analyzing rotational motion in terms of energy.

Equipment:

Computer with Logger Pro software, rotary motion sensor, lab pro, rotating disk apparatus, weight hanger, 50 g mass, 20 g masses, string, short support rod, table clamp, vernier calipers, meterstick.

Introduction Part I:

This experiment uses a disk rotating about a vertical axis through the center of the disk. A string is tied to a pulley which is attached to the disk. The disk experiences a torque, τ, provided by a hanging mass which is attached to the other end of the string as shown in the figure. There is also a small frictional torque, τ_f, which opposes the motion. The net torque determines the angular acceleration, α, of the disk.



We can relate the angular acceleration of the disk to the torques that cause this motion using Newton's 2nd Law in the rotational form,

$$\Sigma \tau = I \alpha,$$ where I is the moment of inertia of the disk

1) $$\tau - \tau_f = I \alpha$$

If the acceleration of the hanging mass, m, is small compared to the acceleration of gravity then $\tau = mgR$ and equation 1 becomes

2) $$mgR = I \alpha + \tau_f$$

If we make a graph of the applied torque, mgR, vs α we should expect to obtain a straight line whose slope is the moment of inertia, I, and whose y-intercept is τ_f. Carefully examine equation 2 and convince yourself that this is true.

Procedure: Part I

Note: In what follows you will need to save the data from each trial that you complete on your floppy disk(A: drive).

1. Tie a length of string to the smallest pulley on the disk by feeding it through the small hole in the pulley. Attach the other end of the string to a weight hanger and hang the string over the pulley on the rotational motion sensor. Cut the string so that its length allows the weight hanger to hang a just a few centimeters above the floor when the mass is in its "down" position. Measure the diameter of the disk pulley using the vernier calipers in two ways: first, with the string wound numerous times around the pulley (when the hanging mass is in the "up" position) and second, when there is no string wound around the pulley (when the hanging mass in the "down position"). Determine R, the radius of the disk pulley by averaging the two

diameters (and dividing by two!). Also measure the height, h, through which the mass falls from the "up position" to the "down position." *It is important that you use this same height in all of the trials that follow.*

2. Connect the rotary motion sensor to the lab pro (to port DIG/SONIC1) and the lab pro to the computer. Start up the Logger Pro software by clicking on its icon in the Physics Apps folder. From the program click on **Open/Mechanics/Rotational Dynamics** to open the file for this experiment. A graph of angular displacement vs time should appear with a sample set of data. Place 50 g on the weight hanger (100 g in all) and check to see that the system undergoes an angular acceleration when released and that the rotational motion sensor turns freely as the hanging mass falls. Click on the **Collect** icon and collect data for 20 seconds while the system accelerates. What should the shape of the resulting curve be for an object undergoing constant angular acceleration? Click on the "x=" icon on the menu bar above the graph and determine the total angular displacement, $\Delta\theta$ (from the "up" position to the "down" position), for the trial just completed.
3. Select a range of data collected during the fall of the hanging mass. Choose **Analyze/Curve Fit/Quadratic** to fit your graph to a function that hopefully matches your data. Record the values of A, B, and C from the computer fit and determine the angular acceleration, α. Now click on the y axis label and select a plot of linear velocity vs time. Click on the "x=" icon and determine the maximum linear velocity of your falling mass. Select **Experiment/Store Latest Run** and repeat this process for two more trials and calculate the average angular acceleration and average maximum linear velocity from the three trials. In your lab book record A, B, and C for each trial as well as the maximum linear velocity. Also, save your data (three sets in all) on your floppy disk in a file named "torque 1".
4. Repeat steps 2-3 above for masses of 120 g, 140 g, 160 g, 180 g, and 200 g, recording and saving three sets of data for each mass as before in files named "torque2", "torque3", etc. Calculate the torque, mgR, applied by the hanging mass for each of the six different trials. Record all data in a neat table.
5. Open the **Graphical Analysis** program and plot the applied torque (mgR) on the y-axis vs average angular acceleration on the x-axis using the data collected in steps 2-4 above. The graph should be linear. From the slope and y-intercept of the graph determine the moment of inertia, I, of the system and the frictional torque, τ_f as discussed in the introduction.

Introduction Part II:

Our equation for conservation of energy is given by

$$\Delta E = W_{nc}, \text{ where } W_{nc} \text{ is work done by nonconservative forces (or torques)}$$

In the case of our rotational apparatus, this equation becomes

$$K_f + U_f - (\overset{0}{\cancel{K_i}} + U_i) = W_f, \text{ where } W_f \text{ is work done by the frictional torque}$$

If we take the initial position to be the "up" (highest) position and the final position to be the "down" (lowest) position this equation becomes

3) $$\tfrac{1}{2} I \omega^2 + \tfrac{1}{2} m v^2 - mgh = -\tau_f \Delta\theta,$$ where ω is the final angular speed of the disk, $\Delta\theta$ is the total angle that the disk rotates through, and v is the final velocity of the hanging mass.

Procedure Part II:

1. Using the fact that $\omega = v / R$, algebraically solve equation 3 for v.
2. Using the result just obtained in part 1, calculate the final velocity of the hanging mass,v, for each of the six trials from the data previously collected.
3. Compare the theoretical velocities calculated in step 2 with the experimental velocities found from your graphs in step 3 of Procedure I. Find the percent difference for each of the six trials. Discuss sources of error in your conclusion.