Name:

Lab Section Number:

Pre-Lab Exercises (the time you spend doing these will decrease the time you spend in lab this week):

1. Calculate the density of the wheel and hub system in the diagram below given that it has a mass, \( M \) and that the fixed axle penetrates through the wheel and hub completely. (hint: consider the volume of the wheel and hub to be the volume of two cylinders minus the volume that the fixed axle removes from the wheel and hub.):

2. If a mass were hanging off the hub as shown, what would the acceleration of the mass be? (Express your answer in terms of a given moment of inertia, \( I \).)
Pre-lab (continued):

3. If a mass were hanging off the hub as shown, and the mass was accelerating with a linear acceleration, $a$, what would the tension in the wire be (express your answer in terms of acceleration, mass of the mass, and the acceleration due to gravity)?

4. What would the torque exerted on the hub and wheel system be?
Introduction: This experiment deals with some of the characteristics of rotational motion. The normal linear quantities, distance \(x\), velocity \(v\), acceleration \(a\) and force \(F\) have rotational equivalents that refer to motion around an axis, rather than along a line. The angular quantities for the linear ones just mentioned are angular displacement \(\theta\), angular velocity \(\omega\), angular acceleration \(\alpha\) and torque \(\tau\). You will be using the relations between these linear and angular variables, as well as the angular equivalent of Newton’s Second Law \(\tau = I \alpha\) throughout this experiment. In doing so, you will determine the moment of inertia (which is represented by the letter I) of a realistic pulley system both experimentally and by theoretical calculation.

Note: Calculations for this lab may be done by hand, as they are the purpose of part of the experiment.

Procedure:

Materials
- Pasco Motion Sensor
- Massive Pulley
- Hangers and Masses (50 and 100 grams)
- Balance
- Meterstick
- Calipers

1. Setting up the computer:
   1.1 Connect the Science Workshop interface to the computer, turn on the interface and then turn on the computer. (this may have already been done for you)
   1.2 Open the Data Studio software package by double clicking on the icon from the desktop menu. Select Create Experiment.
   1.3 In the Experiment Setup screen double-click the Motion Sensor device. This will add them to the interface box diagram, showing the proper connections. Connect the leads as indicated.
   1.4 Double-click the Motion Sensor icon in the Experiment Setup window and set it to collect position and velocity data (under the Measurement tab) at a Trigger Rate of 40 Hz (this is under the Motion Sensor tab).
   1.5 Close the experiment setup window.
   1.6 Under the display window on the lower left, select the type of display you would like. For this experiment we will use a graphs of position and velocity data.

2. Setting up the lab equipment:
   2.1 The wheel and hub system should be assembled for you when you enter the lab. Place the mass hanger at the end of the string hanging off the pulley and place the motion sensor under the hanging mass. The hanger should not
come closer than 20 cm to the motion sensor.

2.2 Make sure the motion detector is in “wide cone” mode.

3. Theory Calculations:

3.1 Mass the rotating disk. Use the calipers to measure the various widths of the wheel indicated in the diagram on the previous page. Subtract the mass of the axle by massing one of the provided axles next to the balance and subtracting that mass from the mass of your wheel+hub+axle.

3.2 Calculate the density the wheel and hub (you may completed the formula in the pre-lab already). You must show the actual calculation, not just an answer!

3.3 Calculate the moment of inertia of the wheel and hub (Hint: the moment of inertia of a single cylinder or disk rotating the way this system does is:

\[ I_{cylinder} = \frac{1}{2} M (R_1^2 + R_2^2) = \frac{1}{2} \rho V (R_1^2 + R_2^2) = \frac{1}{2} \rho \pi h (R_2^2 - R_1^2)(R_1^2 + R_2^2) = \frac{\rho \pi}{2} h (R_2^4 - R_1^4) \]

In this equation, \( \rho \) is the density of the cylinder, \( h \) is the cylinder’s thickness, \( R_2 \) is the outer radius and \( R_1 \) is the inner radius. You will need to use this formula in slightly modified manner.) Again, you must show the actual calculation, not just an answer!

4. Taking data:

4.1 Obtain the masses of the hanger and the two masses provided. (Remember to use the mass in kilograms for all your calculations.)

4.2 Using a meterstick, measure the length of the string as it is fully extended, be sure to include this data in your report.

4.3 Place the empty hanger on the string hanging off the hub, ensure that it is stationary and start collecting data for a second before letting the mass fall. Stop collecting data sometime after about fifteen seconds. The first portion of your graph, indicating only the initial descent of the mass should look similar to the one at the left.

4.4 How long did it take for the mass to reach the bottom? Collect this data (starting from the time when the velocity becomes negative).

4.5 Select the first downward sloping straight line on the velocity vs. time graph and perform a linear fit on it using the fit/linear command in the menu immediately above the graph. Note all the fit parameters and include them in your lab report along with proper units.

4.6 What happens to the position vs. time graph if you let the system keep running?

4.7 What effect does this have on the data you are collecting?

4.8 Why does the mass move this way after it has descended initially?
4.9 Print the split position vs. time and velocity vs. time graphs as seen above (landscape, on one page). The axes should be labeled and the time axes “locked” to a common time base using the “lock” button immediately above the graph.
4.10 Collect motion data (as well as the time of descent) for the hanger loaded with one and two masses.

5. Data analysis:
5.1 Construct a torque vs. angular acceleration graph in a spreadsheet program such as Excel (provided on the computers in the lab). You will need to calculate these values from each set of motion data you collected. (Hint: You will need to use the definition of torque as well as the formula to calculate angular acceleration from linear acceleration.)
5.2 The data should lie on a straight line. Add a linear trendline to the graph and obtain an equation for this trendline as well as the R-squared value for your fit. (In Excel, this can be accomplished by right-clicking on the data, choosing “Add Trendline,” selecting linear, and selecting “Display equation on chart” as well as “Display r-squared value on chart” under the “Options” tab.)
5.3 What physical quantity does the slope of this trendline represent?
5.4 Print this graph after you have checked it with your theoretical calculation to ensure that it is reasonable.
5.5 Print the spreadsheet you used, and ensure that all your collected data are also on this spreadsheet.

6. Questions:
6.1 Your mass “fell” a distance that you measured in step 4.2. This, in turn, caused the wheel and hub system to rotate through an angle. What angle did it rotate through? (Show your calculation for one case, and the answers for the remaining two.)
6.2 Using the appropriate linear kinematics formula for a constantly accelerating mass, the data collected in step 4.2 and the “time of descent” data collected in steps 4.4 and 4.10, what was the acceleration of each mass? (Show your calculation for one case, and the answers for the remaining two.) Do these values compare favorably to the values you obtained via trendline analysis of your velocity data?
6.3 What were the angular accelerations of these systems as calculated from your answer to 6.2? (Show your calculation for one case, and the answers for the remaining two.) Do they compare favorably to the values you used in your excel spreadsheet?
6.4 How does your theoretical moment of inertia compare to your experimental value? (Use a percent difference calculation to answer this question, and show the calculation. Use the theoretical moment of inertia as the “accepted” value.)
6.5 What physical reasons might there be for the difference between your theoretical calculation for the moment of inertia and your experimental result?