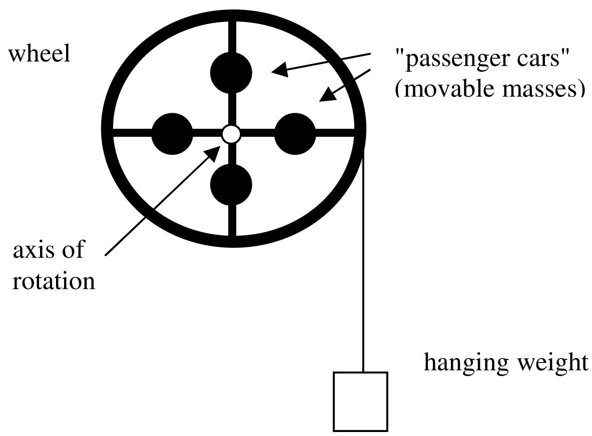
Physics 200B
Lab 10: Rotational motion

Objectives:

- To investigate rotational motion with constant angular acceleration.
- To determine the moment of inertia of a complicated system.
- To see how the moment of inertia affects angular acceleration.

Overview:
When an unbalanced torque is applied to an object, it will cause an angular acceleration. The angular acceleration of the object is proportional to the torque and inversely proportional to the object's moment of inertia. The moment of inertia is influenced by the mass of the object and how that mass is distributed with respect to the axis of rotation.

In this lab, you are being asked to test a scale model of a carnival ride in order to determine its characteristics. The model consists of a vertically mounted wheel with low-friction bearings. The wheel can carry four cars (for passengers) at various distances from the axis of rotation. A weight hanging from a string which is attached to the outside rim of the wheel provides an acceleration for the system. (See the diagram below.)



Your task is to determine the moment of inertia of the wheel, and to come up with a way of predicting the acceleration of the weight, if the location of the passenger cars and the value of the hanging weight is known. You have available to you a computer with motion detector, and a variety of weights that can be used to accelerate the wheel.

The manufacturer of this scale model has provided you with some data regarding the dimensions of the wheel:

Outer radius: 0.20 m

positions of movable masses (measured from axle):

position	distance from axle (m)
1st	0.075
2nd	0.100
3rd	0.125
4th	0.150
5th	0.175

Activity 1: Finding the moment of inertia of the unloaded wheel

1. Place the motion detector underneath the hanging mass. Start Logger Pro and open the experiment file **Rotation_wheel**. Remove the four movable masses from the wheel.

2. Derive a relationship between the wheel's moment of inertia and the acceleration of the hanging weight (or use the relationship you derived for prelab). This relationship should depend on m (the mass of the hanging weight), R (the outer radius of the wheel), and g, as well as the acceleration of the weight, a. The motion detector is set up so motion toward the motion detector (down) is positive.

3. Hang 20 g from the wheel. Begin recording data, and let the hanging mass drop. From your data, determine the mean acceleration of the hanging mass and the uncertainty in the acceleration. What is the best way to determine the mean acceleration? Record your results.

4. Use the relationship you derived to calculate the moment of inertia of the wheel, based on the mean acceleration. Using the mean acceleration gives you a "best" estimate of the moment of inertia. Hint: if you do this in Excel, you can reuse the calculations for later parts of the lab.

5. Find the experimental uncertainty in the wheel's moment of inertia as follows.
First, repeat the calculation with the lowest value of the acceleration's error range (acceleration minus the uncertainty in acceleration) in order to get an upper limit on the moment of inertia.

Now repeat the calculation with the highest value of the acceleration's error range (acceleration + uncertainty in acceleration) in order to get a lower limit on the moment of inertia.

Question 1: Explain briefly but carefully why using the lower limit on acceleration gives an upper limit for the moment of inertia.

! Checkpoint 1

6. Repeat steps 3-5 with the hanging mass equal to 25 g. Hint: you can use Excel to simplify the process.

7. Repeat steps 3-5 with the hanging mass equal to 30 g.

8. Repeat steps 3-5 with the hanging mass equal to 35 g.

9. Repeat steps 3-5 with the hanging mass equal to 40 g.

Question 2: Do the five "best" values you obtained for the moment of inertia of the wheel agree with each other, within experimental uncertainty (use the “two standard deviation” rule)? Explain.

Note that the uncertainty range, as we've defined it, will include the "true" value only about 90% of the time. If only four of the five values agree with each other, that's not necessarily a problem.

10. Find the average of the five "best" values of the moment of inertia of the unloaded wheel. Also determine the uncertainty in the result by finding the standard deviation of these values.

! Checkpoint 2

Activity 2: Finding the angular acceleration of the loaded wheel

Now we'll load the wheel by attaching the four masses ("passenger cars") at the second position (the second hole out from the axle).

1. Find the mass of each of the "passenger cars." Record your results.

2. Calculate the moment of inertia of the wheel including the “passenger cars” in the second position. To do this, use the measured masses of the “cars,” the best (average) value of the wheel’s moment of inertia determined in the previous activity, and data given on the first page of the lab writeup. When you have done this calculation, also calculate an error range for this value, using the uncertainty in the moment of inertia of the unloaded wheel (found in the previous activity).

3. Use this calculated moment of inertia to predict what the acceleration of the hanging weight will be if a 20 g mass is used to accelerate the wheel with passenger cars in the second position. Calculate an uncertainty in this acceleration.

4. Carry out a measurement of the acceleration of the hanging 20 g mass. Record your result.

Question 3: Does the experimentally determined acceleration agree (within uncertainties) with the one you predicted? Explain briefly how you concluded this.

5. Calculate the angular acceleration of the wheel.

Question 4: If the hanging mass were 40 g instead of 20g, would your values for the following quantities change, and if so, would they increase or decrease in magnitude? Why?

moment of inertia of the loaded wheel:

acceleration of the hanging mass:

angular acceleration of the wheel:

! Checkpoint 3

Activity 3: Dependence of the angular acceleration on the positions of the cars
Prediction: If the masses (passenger cars) are moved out to the position farthest from the axis, will the angular acceleration of the wheel be bigger, smaller, or the same, compared to what it is when the masses are in the second position, closer to the axis? Assume a 20 g hanging mass is used in both cases. (Hint: think about what happens to the moment of inertia.)

1. With the masses in the farthest position, carry out the measurement of the acceleration of the 20 g hanging mass. Record your result and its uncertainty.

2. From the measured acceleration, determine the angular acceleration and its uncertainty.

Question 5: Did your result agree with your prediction? If the masses could be moved even farther from the axis, would you expect the angular acceleration to increase or decrease, if the same hanging weight is used? Explain briefly but carefully why the angular acceleration is affected by the position of the movable masses.

! Checkpoint 4

Question 6: Suppose we decide that what makes this ride exciting is the tangential acceleration of the "passenger cars." For this part of the lab, you'll use passenger cars of double the mass (two "cars" fastened together) to make the effects easier to see. Let's examine the ride to see which position of the cars would give the cars the largest tangential acceleration. Assume the hanging weight stays the same throughout.

a) Describe in words how the angular acceleration will change as the cars are moved to larger distances from the axis of rotation.

b) Describe in words how the tangential acceleration of the cars will change as the cars' distance from the axis increases.

c) Under these conditions, do you think the tangential acceleration of the cars will be the largest when the cars are close to the axis, far from the axis, or somewhere in between? Explain your reasoning.

d) Will using a different hanging mass modify your answer to c)?

3. Choose a hanging mass that gives a reasonable acceleration and record its value: ________

For each of the five positions of the cars, measure the acceleration of the hanging weight, and then calculate the angular acceleration of the wheel and then the tangential acceleration of the cars. Record your data and calculations below.

position	a (m/s^2)	α (rad/s^2)	a_t of car (m/s^2)
1			
2			
3			
4			
5			

4. Plot the tangential acceleration vs. the distance from the axis using Excel. Explain why the graph looks the way it does. Does the position at which the tangential acceleration is highest agree with your prediction in question 6c?

! Checkpoint 5