Moment of Inertia: Rotational Energy

Name____________________ Partners______________________ Lab Day/Time___________

Pre-Lab

You are required to finish this section before coming to the lab; it will be checked by a lab instructor when the lab begins.

Read over the procedure for this lab. Then, review your textbook sections on the kinematics of a rolling object. Make sure you understand the relationship $\mathbf{v} = \boldsymbol{\omega} r$: this equation relates angular velocity $\boldsymbol{\omega}$ with translational (linear, or straight-line) velocity $\mathbf{v}$ for a rolling object with radius r.

1) Write the equation that defines each of the following:

a) translational kinetic energy

b) rotational kinetic energy (in terms of $\boldsymbol{\omega}$ and in terms of $\mathbf{v}$)

c) moment of inertia of a cylinder of mass m and radius r, rotating about its symmetry axis

2) It isn't too difficult to spin one of the wheels on a toy car, but it takes a surprising amount of effort to spin a bicycle wheel on its axle, even if you can neglect friction in both cases. Explain why in terms of moment of inertia.

3) A bicycle wheel can be thought of simply as a central solid cylinder (the part that attaches to the axle) surrounded by a thin shell of mass (the rim and tire) located along the outer edge of the wheel. Compared to these parts of the wheel, the mass of the spokes is small enough to be neglected. A sample bicycle wheel has mass 2.0 kg, half of which is in the central cylinder. The other half is in the rim and tire. The central cylinder has a radius of 4.0 cm. The wheel has a radius of 40.0 cm.

a) What is the moment of inertia of the central cylinder?

b) What is the moment of inertia of the rim/tire? *Hint: you should not be using the same equation you used in (a).*

c) The moment of inertia of the entire wheel is just the sum of the individual moments of inertia of the parts. What is the moment of inertia of the wheel?

The wheel described above rolls down a ramp without slipping. It starts rolling on the ramp at a point where the ramp is 2.0 m above the ground. Any energy lost to frictional effects as the wheel rolls is negligible.

d) What gravitational potential energy (relative to the ground) does the wheel have at the top of the ramp?

e) What types of mechanical energy does the wheel have when it reaches the ground?

f) How fast is the wheel moving at the bottom of the ramp? *Hint: This is asking for the translational velocity of the wheel. You need to set up an energy conservation equation in which you can isolate the translational velocity as the only unknown quantity.*

g) Assuming acceleration is constant, what is the *average* translational velocity of the wheel as it rolls down the ramp? *Hint: since the wheel started from rest, the relationship between the average velocity and the velocity at the bottom of the ramp is quite simple.*

End of Pre-Lab

Lab Equipment

Metal wheel
Metal rails
Stopwatch
Tape Measure

Procedure

1) Measure the thickness of the metal block provided. You will use the block to raise one end of the rail assembly. Each group member should measure independently. Record your data below.

2) Position the disk at the upper end of the track with its axle resting on the rails and the disk itself between them. Roll the disk as far up the track as possible. Since the forward edge of the disk is going to hit the stop at the bottom of the track, use the forward edge of the disk as its starting location and move the metal block to a point directly beneath this starting position. *Question: Why will this make your data analysis easier than putting the metal block under the end of the track? Be specific.*

3) Measure the time it takes for the disk to roll from the top to the bottom of the rails. Repeat this measurement enough times to give yourself a good idea of its uncertainty. Record your data in the space below.

Question: As you see the lab in progress, describe what physical factors may contribute to uncertainty in your results. Do not just list the factor – describe <u>*how*</u> *it will reasonably affect your measurements or calculations.*

4) Now, in the space below, make any other measurements you think you will need to determine the average speed of the disk as it moves from top to bottom of the rails.

5) Measure the dimensions of the disk and axle. The disk and axle are made of iron, so you may also need to know the density of iron (7874 kg/m^3) to complete your calculations. Make sure to have all lab group members perform independent measurements.

In-Lab Data Analysis

1) Calculate the separate and combined masses of the disk and axle based on your best values for their measured dimensions. Show all calculations below.

2) Describe how you would calculate the rotational kinetic energy of the disk and axle based on your lab data without solving for its moment of inertia or angular velocity.

Talk with an instructor before you leave the lab.

Name:________________________________ Section:________________________

Homework Problems

Use appropriate uncertainty analysis to answer the following questions. Show all calculations clearly and include all units in your calculated values.

1) What is the change in potential energy of the disk and axle from the top to the bottom of the rails?

2) What is the final linear (translational) speed of the disk and axle at the bottom of the rails?

3) What is the final linear kinetic energy of the disk and axle?

4) Neglecting energy loss due to friction, what is the rotational kinetic energy of the disk and axle at the bottom of the rails?

5) Using your lab data, calculate the angular velocity of the disk and axle at the bottom of the rails.

6) You should now be able to calculate values for the moment of inertia of the disk and axle in two different ways.

a) From your lab data and calculations so far, you should be able to solve for a value for the moment of inertia of the disk and axle without using the equation for the moment of inertia of a cylinder. What is this value for the moment of inertia?

b) Now, calculate the moment of inertia of the disk and axle using the equation for the moment of inertia of a cylinder.

c) How closely do your results from (a) and (b) compare? Calculate the percent difference in the best values.

7) In the analysis, you ignored energy lost to frictional effects. If you accounted for this energy, how would your result for **I** differ – would it be larger or smaller? Explain.

8) In fact, this experiment would not work at all if there were no friction. Explain why.

9) Suppose the lab group next to you had a disk and axle made of iron with the same mass as the one you used (but you never actually saw the disk and axle they used). Their rails were set up exactly the same as yours. In neither case did the disk slip – it rolled the whole time it moved down the rails. However, their disk reached the bottom of the rails in much less time than yours. All results are valid (no tricks are being played!!) Explain how this might happen.