Lab Section (circle):
Day:    Monday        Tuesday
Time:  8:00  9:30  1:10  2:40

Moment of Inertia: Rotational Energy

Name_________________________ Partners____________________________________

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 \( v = \omega r \): this equation relates angular velocity \( \omega \) with translational (linear, or straight-line non-rotating) velocity \( v \) 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 \( \omega \) and in terms of \( v \))
   
   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 (note the unit!). 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 (plural!) 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; go back to your kinematics equations!*

**End of Pre-Lab**
Lab Equipment

- Metal wheel
- Stopwatch
- Metal rails
- Tape Measure

Procedure

1) The metal block provided is used to raise one end of the rail assembly to create an incline on which the metal disk/axle will roll. Measure the thickness of the metal block; each group member should measure independently to establish uncertainty. Record your data below and use worst case analysis to find the thickness with its uncertainty.

2) Position the disk/axle at the upper end of the rails with its axle resting on the rails and the disk itself between them. Roll the disk as far up the rails as possible. Since the forward edge of the disk is going to hit the stop at the bottom of the rails, 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 rails? 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.

4) As you see the lab in progress, describe what physical factors may contribute to uncertainty in your time measurements. Do not just list the factor – describe how it will reasonably affect your measurements or calculations.
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 \((7874 \text{ kg/m}^3 \pm 1 \text{ kg/m}^3)\) to complete your calculations. Make sure to have all lab group members perform independent measurements to establish uncertainty.

6) 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.

**In-Lab Data Analysis**

1) Use the Excel spreadsheet provided on the lab computers to calculate the masses of your disk and axle and their uncertainties. Write the results for best masses and uncertainties 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.*
Homework Problems

In the homework section, you will be calculating the moment of inertia of the Disk/axle using two methods. First, you will use your data describing the motion of the disk as it rolled down the rails. Then you will perform a direct calculation using the equation for moment of inertia from question 1c in the pre-lab.

Use appropriate worst-case uncertainty analysis to answer the following questions. Show all calculations clearly and include uncertainty and units in your calculated answers. Use the calculations from the Excel spreadsheet for masses and uncertainties.

I. Moment of Inertia Calculation – Method 1: Rotational Energy. By answering the following questions, calculate the rotational kinetic energy of the disk/axle at the bottom of the rails. Then, using the rotational kinetic energy, find the moment of inertia of the disk/axle. The method should be roughly the same as you described in your answer to in-lab data analysis question 2. DO NOT use a direct calculation for moment of inertia (using an equation such as the one in pre-lab question 1c) at any part in this method.

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) Calculate the angular velocity of the disk and axle at the bottom of the rails. *Hint: be careful about the radius you use in this calculation!!*

6) What is the moment of inertia of the disk/ axle?

III. Comparison of Data/Conclusion Questions

1) Compare your results for moment of inertia from the two methods used. Calculate the percent difference in the best values and indicate whether they agree within their ranges of uncertainty.

2) In the analysis, you assumed energy lost to frictional effects was zero. If you could actually measure and include the frictional energy in your calculations, how would your moment of inertia result calculated using the Rotational Energy Method differ – would it be larger or smaller? Explain.
3) In fact, this experiment would not work at all if there were no friction. Explain why.

4) 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.