

ROTATIONAL MOTION

I. Introduction

This lab will be very different from all the others in the course. Rotational motion can be very counter-intuitive. So instead of concentrating on data and analysis, the focus of this lab is on personally experiencing some of the effects. It's also kind of fun, although actually enjoying any of this is strictly forbidden and will be severely punished. **Read Chapter 8 of your textbook before coming to lab.** It contains the background you need to understand rotational motion (and this lab).

The equipment for this lab is very large, and so there is only a single set-up for most phases of the lab. You can do the sections of the lab in any order. Your TA will give you appropriate marching orders, and may ask you to form larger groups than usual.

This lab will take longer than usual. You can defer detailed analysis and pretty pictures until later, but don't leave the lab room until you really understand why things behave as they do. This will be tricky for the gyroscopes!

In each of the sections below, the write-up will ask you questions. They are not rhetorical. Answer them in your lab book. No error analysis is required. Concentrate your attention on the essential physics.

II. The Merry-Go-Round

1. You have a stopwatch and a meter stick at your disposal. Give the merry-go-round a good shove so that it makes it around three times easily without stopping, and calculate its average angular velocity for the first three revolutions. What is its average period of revolution? Its mean frequency of revolution? Calculate the average translational velocity of a point on the edge of the merry-go-round in meters/second.
2. Design an experiment to actually measure the translational velocity of a point on the rim and try to verify the relationship between v and ω that you assume in step 1 above. There should be some string and some tape around to help with this. Make a sketch in your notebook that indicates the direction and magnitude of various points on the merry-go-round.
3. Give the merry-go-round yet another shove and determine its angular acceleration. Is this acceleration constant as a function of time?
4. Fit the metal bar into the center pole of the merry-go-round. Try giving the merry-go-round the same acceleration while pulling or pushing at different points along the bar, from all the way in at the middle to all the way out at the end. Everyone in the lab group must do this. Record your observations and explain them.
5. Add some weights to the merry-go-round. Try giving the merry-go-round a constant acceleration again, but this time with the weights at different positions. Record your

observations. Does it matter where *around* the merry-go-round you put the weights, or only how far from the center? Again, everyone in the lab group must try this.

- Two people in the lab group should sit on opposite sides of the merry-go-round while the other group members set the merry-go-round spinning. (Careful! No injuries/lawsuits, please.) The two people sitting on the merry-go-round should play catch with the soccer ball once the merry-go-round is spinning nicely. Does the ball pass directly over the center pole? Is the path of the ball curved or straight?

III. The Small Gyroscope

Every lab group should have their own small gyroscope to play with. Enjoy!

- Start the gyroscope spinning using one of the battery powered motors in the lab. Don't get it spinning too fast or it will come apart. Position the gyroscope frame so that the rotation axis is horizontal. Place one end of the frame on the little plastic base and try to release the other end so that the gyroscope precesses uniformly (without bobbing up and down). Describe how you had to release the gyroscope to make this work. (Everybody try this.)
- Draw a reasonably careful picture of the precessing gyroscope in your lab notebook. Add vectors for all the forces acting on the gyroscope, and for its angular momentum. Pick a point about which to calculate the torque acting on the gyroscope, and draw a vector for that as well. Explain why the gyroscope precesses, drawing additional pictures if necessary.

IV. The Big Gyroscope

There is a large gyroscope made from a bicycle wheel which sits on a rotatable base.

- Start the gyroscope spinning with its axis horizontal. Get it spinning as fast as you can. Hang a weight off one end of the axle. Observe the motion. Take the weight off and hang it on the other end of the axle. (You may have to spin up the wheel again.) Draw diagrams to explain the motion of the wheel.
- Spin up the wheel and observe the motion as the amount of hanging weight is varied. Record your observations and explain them.
- Spin up the wheel and don't hang a weight on it. Instead, rotate the base by hand. Observe what happens. Spin it up again and rotate the base the other way. What is different this time? Can you explain what happened?

V. The Rotating Stool

- Have one person in the group hold the bicycle wheel with the axle pointing straight out while another spins up the wheel as fast as possible (one of those battery powered gizmos is reported to work well). When the wheel is spinning nicely, try to tip the axle up. What happens? What do you feel? Try tipping it down, and to the left and right. Everyone in the group *MUST* try this! Explain what is going on.
- Repeat the above experiment with the person holding the bicycle wheel sitting on the rotating stool. What happens now? Does it make sense? Draw diagrams to explain.

Be sure to diagram the torque applied to the wheel. Everyone in the group should get a turn on the stool.

3. Sit on the stool holding the two heavy masses straight out to the sides at arms length. Start spinning *SLOWLY* and then draw in your arms. Explain what happens. Push your arms back out. Explain again. Everyone gets to do this.
4. Take quantitative data for at least one group member holding the weights. The other group member(s) should determine ω with the weights out and with the weights in. Determine the ratio of moments of inertia for the two situations. Then determine the ratio of kinetic energies. When the person on the stool pulled in the weights, did the kinetic energy go up or down? Explain this result. Where did energy come from? Or go?

VI. Tops

Try out the various tops in the room.

1. Draw a free body diagram of a standard top. Then draw a diagram showing the angular velocity, and torques acting on it. Use this diagram to explain briefly why tops precess.
2. Notice that the round-bottomed tops (sometimes called "Tippee Tops") will flip themselves over and spin on their spindles. Experimentally confirm that the center of mass of the top is not in the center of the sphere, but is close to the "bottom" of the Tippee Top.
3. Notice what happens to the angular velocity of the top when it flips over. Can you qualitatively explain this?
4. Can you explain why the top flips over? On the last page of this lab are two pictures of the Tippee top. You may want to paste them into your lab book.

If you carry out the analysis below and think you really understand why the top flips over, you might want to try the following experiment: hold the top horizontal on the table or floor and flick the handle very hard with a finger to set it spinning. If you set it going hard in enough, it will stand up on its handle.

On the first diagram of the tilted top draw the following vectors: angular velocity, angular momentum, kinetic friction between the top and the table, and the position vector from the center of mass to the point at which the frictional force is applied. Finally, draw in the torque produced by this frictional force. Would this torque tend to make the top flip over?

On the second diagram of the horizontal top, draw in all the vectors named above plus any other forces acting on the top. Draw in the additional torques that these forces cause and describe the resulting motion. Does the torque due to the frictional force between the top and the surface of the table still tend to make it flip over? Why don't ordinary tops flip over the way Tippee Tops do?

