Walk-in Lab 12
Angular Momentum
Physics 121

CID(s): ________________________

Description

Today you get to play with angular momentum. We’ll look at the conservation of angular momentum and also at what happens when a torque is applied perpendicular to the angular momentum. Don’t get too dizzy! Work together and have a good time. Let me know how things go and email me ideas for making the lab better. Have a great day!

Objective: To study angular momentum with and without external torques.

Equipment: Rotating platform, dumbbell weights, bicycle wheel, rotating arm with moveable weights, and three rotation-period timers.

Part A – Conservation of Angular Momentum

For the first part, we’ll look at conservation of angular momentum. You will find in the walk-in lab a rotating arm with moveable weights, like this:

![Diagram of rotating arm with weights](image)

The weights have strings tied to them and the strings go through some little loops near the axis of rotation. When you pull down on the handle hanging from the pulley attached to the ceiling the weights will move in, towards the rotation axis. This changes the rotational moment of inertia $I$, but there is no torque applied. (Do you know why? Think about the formula $\vec{\tau} = \vec{r} \times \vec{F}$.)

Your job is to calculate the moments of inertia when the weights are in the two different positions and to show that the rotation period changes as required by conservation of angular momentum. The stops are placed on the rotating rod so that the masses move from outer radius $R$ to inner radius $R/2$. ($R$ is given in the table on the metal base of the apparatus.) The mass $M$ of each weight is also given in this table, as is the length of the rod $L$, and the mass of the rod $m$. The total rotational moment of inertia is the sum of moments of inertia of the rod and of the two weights.

On the back of this sheet, derive an expression for the ratio $I_{\text{out}}/I_{\text{in}}$, where $I_{\text{out}}$ and $I_{\text{in}}$ are the total rotational moments of inertia when the masses are “out” and “in.” Substitute the values given on the base of the experiment into your formula and record your result here:

$$\frac{I_{\text{out}}}{I_{\text{in}}} = \text{(a number)}$$ (1)

The angular momentum is $L = I\omega$, and the period of rotation is $T = 2\pi/\omega$. On the back of this sheet, show that conservation of angular momentum requires that

$$\frac{T_{\text{out}}}{T_{\text{in}}} = \frac{I_{\text{out}}}{I_{\text{in}}}. \quad (2)$$
OK. Now let’s make some measurements. Use the laser/timer setup to measure the rotation period accurately. Since some of the angular momentum is lost due to friction, we have to average the measurements. Start the arm rotating with the weights in the “out” position. Measure $T_{\text{out}}$ by pushing the reset button on the first timer. When a reading shows up on this timer pull the handle (listen for the click when the weights hit the stops) and measure $T_{\text{in}}$ by pushing the reset button on timer 2. Now release the strings and measure $T_{\text{out}}$ again by pushing the reset button on timer 3. Record your results, then average the two $T_{\text{out}}$ measurements (timers 1 and 3) and divide by $T_{\text{in}}$ from timer 2 and record this ratio. (Averaging gives you a value for $T_{\text{out}}$ that is comparable to what it was when $T_{\text{in}}$ was measured, eliminating error due to friction. Making the measurements as quickly as you can will also help keep the effect of friction small.) Write your result here:

\[
\begin{align*}
\text{first } T_{\text{out}} &= \underline{\text{ }} \\
T_{\text{in}} &= \underline{\text{ }} \\
\text{second } T_{\text{out}} &= \underline{\text{ }} \\
T_{\text{out,avg}}/T_{\text{in}} &= \underline{\text{ }} (3)
\end{align*}
\]

How does your ratio compare to your prediction from Eq. 2? If you are careful, but work fast, you can get your error down to 5%, or better.

You can do a similar qualitative experiment by using the rotating platform. Sit or stand on it (be careful) and have someone start you spinning slowly while you hold the dumbbell weights out. Pull them in and notice how your rotation speed changes. Again, be careful!

**Part B – Vector Angular Momentum**

Now let’s think about what happens when you stand on the rotating platform holding a rotating wheel. I’ve sketched a wheel and a coordinate system in this drawing:

When you apply the forces $F_y$ as shown, you will start to rotate counter clockwise around the $y$ axis.

The equation that helps us understand this is

\[
\vec{\tau}_{\text{external}} = \frac{d\vec{L}}{dt} \approx \frac{\Delta \vec{L}}{\Delta t} \Rightarrow \Delta \vec{L} \approx \Delta t \vec{\tau}_{\text{external}} (4)
\]

The angular momentum vector points along the positive $z$ axis. When you apply forces as shown in the diagram, the torque they produce is $\vec{\tau} = \vec{r} \times \vec{F}$. The vector $\vec{r}$ in this case points from the center of the wheel to the place where you apply the force (the handle), so the torque (remember the right-hand rule) points in positive $x$ direction. This means that the tip of the angular momentum vector will move from where it points initially toward the positive $x$ direction, which means that you will start to rotate counter-clockwise. Make sure that you understand this paragraph before you go on; it’s a little tricky.

Try this! Spin the wheel up, hold it horizontally, step carefully onto the rotating platform, and turn the wheel handle. Notice that you can rotate yourself in either direction depending on how you twist the handle. You don’t need numbers, but check this box to let me know that you (or some brave person in your group) tried this part.

□ I (or we) tried this (and survived).