ROTATIONAL COLLISIONS

What happens when two rotating objects collide and then rotate together? How can this complex interaction be modelled and predicted? What quantities remain constant?

Objectives

- Accurately measure the angular velocity just before and just after a collision.
- Learn how to construct a model and modify it based on measured data.
- Learn how to predict the result of a complex collision between rotating objects.

Materials and Equipment

- Data collection system
- Wireless Rotary Motion Sensor
- Small rod, 45-cm
- Rotational Inertia Accessory (including long screw)
- Table clamp or sturdy base
- Small rod, 45-cm

Safety

Follow regular laboratory safety precautions.

Procedure

1. Measure the mass and radius of one of the two identical solid disks and the ring and enter the values in the space above Table 1.

2. Attach the table clamp, rod, and rotary motion sensor as shown in Figure 1.

3. Remove the metal screw from the top of the rotary motion sensor and remove the pulley and place it aside.

4. Notice a small rectangular indentation in the center on one side each disk. Attach one of the disks to the rotary motion sensor by placing the indentation side down over the metal shaft and re-attaching the metal screw. You may need to hold the shaft still with a finger to tighten it securely. If it doesn't tighten, you may have the wrong screw. There is a longer one that comes with the disks and rings. Save that one for later.

5. Connect the rotary motion sensor to your data collection system. Change the data collection rate to 100 Hz. Create a graph display of angular velocity versus time.

6. Give the disk a slow spin and practice dropping the other disk with its indentation side down onto it. It should land in the center and become flush with the lower disk. Make sure you are not touching the dropped disk when it comes in contact with the lower disk.

7. Predict what will happen to the initial angular velocity when the second disk is dropped on the first. Will the angular velocity increase, decrease, or stay the same? If the initial angular velocity is 10 r/s, what will the final angular velocity be? It is OK to make an incorrect prediction.
8. Start data collection and give the disk a slow counter-clockwise spin. A clockwise spin will result in negative values for angular velocity. Watch the angular velocity value. When it approaches 10 r/s, drop the second disk. If it lands so that it is flush with the lower disk, stop recording. Otherwise try again.

9. Locate the part of the graph that shows the collision. It will show a gradually decreasing angular velocity followed by a steep drop that occurs in a fraction of a second, then a resumption of the gradual decrease. The gradual decrease is due to friction in the rotary motion sensor. The steep drop is from the mutual friction between the disks during the collision. Use the tools of your data collection software to find the angular velocity just before the steep drop. This is the initial angular velocity, record it in Table 1. Find the angular velocity just after the steep drop. This is the final angular velocity, record it in Table 1. It can help to expand the vertical axis to accurately measure these 2 data points.

10. Revisit your prediction for the final angular velocity. Were you correct? Explain how the data justified or refuted your prediction below.

11. Repeat for another collision except this time drop the disk when the angular velocity is approaching 20 r/s, then 30 r/s, 40 r/s, and 50 r/s. Record the data for all the trials in Table 1.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Initial Angular Velocity (r/s)</th>
<th>Final Angular Velocity (r/s)</th>
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<tr>
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11. Plot a graph of initial angular velocity, $\omega_0$ on the vertical axis and final angular velocity, $\omega$ on the horizontal axis on the blank Graph 1 axes. Be sure to label both axes with the correct scale and units. Draw a best-fit line using a straight edge.
Graph 1: Initial angular velocity versus final angular velocity

12. Pick 2 points on your best fit line and calculate the slope. What are the units of your slope? What do you think it represents? Show your work below.

13. Predict what will happen to the initial angular velocity if, instead of the second disk, the ring is dropped on the rotating disk. If the initial angular velocity is 10 r/s, what will the final angular velocity be? Explain the reasoning behind your prediction, show calculations, if any. It is OK to make an incorrect prediction.

14. Remove the disk from the rotary motion sensor, you may need to place your finger on the shaft to hold it as you untighten the screw. An alignment guide is a black plastic piece with 3 arms. It is used to help catch the ring during a collision. Insert the screw through one of the alignment guides, then reattach the disk so that the alignment guide is on top and flush with the surface of the disk. You may need to hold the shaft still with a finger to tighten the screw securely. See Figure 2.

15. Start data collection and give the disk a slow counter-clockwise spin. Watch the angular speed value. When it is approaches 10 r/s, drop the ring onto the disk. Use the tools of the data collection software to find \( \omega_0 \) and \( \omega \). Record the results below. Revisit your prediction for the final angular velocity. Were you correct? Explain how the data justified or refuted your prediction below.

\[ \omega_0 = \, \text{_____ r/s} \quad \omega = \, \text{_____ r/s} \]
16. Many students predict that dropping the disk resulted in a final angular velocity that is about half of the initial. They also notice the two disks had equal mass and that the mass of the ring is almost the same as a disk. It is logical and reasonable to assume that the ring will have the same effect. However, there is another factor involved with rotation. In addition to the mass, the location of the mass relative to the center of rotation is important. It is harder to rotate a mass as you move it further away from the center. The disk has mass distributed from the center to the edge while the ring has all its mass at the edge. This makes the ring harder to rotate than the disk even though they have about the same mass and radius. A measure of how hard it is to rotate an object about a point is called rotational inertia. Its symbol is $I$. The slope of the line of your graph is the ratio of the final rotational inertia (both disks) to the initial rotational inertia (one disk). Knowing this, use the data from the ring/disk collision to estimate the ratio of the rotational inertia of the ring to the disk, $I_R/I_D$. Show your work below.

17. The rotational inertia of basic shapes can be calculated. Each shape has a different equation. For a disk rotating about its center the equation is: $I_D = \frac{1}{2}mr^2$. For a thin ring rotating about its center the equation is: $I_R = mr^2$, where $m$ is the mass of the object and $r$ is its radius. Using these equations and your measured values for their masses and radii, calculate each object’s rotational inertia and the ratio of $I_R/I_D$. Compare your result to your prediction for $I_R/I_D$.

18. We can write an equation for the graph now that we know the slope is the ratio of the final rotational inertia (both objects added together) to the initial rotational inertia (disk alone), $I/I_0$. Use the equation for a straight line, $y = mx + b$. Replace $y$ with $\omega_0$, $x$ with $\omega$ and the slope $m$ with $I/I_0$. The $y$-intercept $b$ is the initial angular velocity if the final angular velocity is zero. This should be zero. Show your result below.

19. The equation for your graph is usually arranged in this form, $I_0\omega_0 = I_0\omega$. The quantity $I_0\omega$ is called angular momentum and has the symbol $L$. Angular momentum is a conserved quantity like linear momentum and energy. In a collision, angular momentum is constant if the sum of the external torques on the system is zero. In this experiment there was an external torque from the friction in the rotary motion sensor. However, during the short interval of the collision, we can neglect this torque and use conservation of angular momentum to predict the outcome of the collision. Predict the ratio of $\omega_0/\omega$ for a collision between the ring and two disks rotating together. Use the equation $I_0\omega_0 = I_0\omega$ and your values for $I_D$ and $I_R$. Show all of your work below.

20. Test your prediction by attaching the two disks with an alignment guide to the rotary motion sensor using the longer screw that came with the disks and rings. Drop the ring and measure $\omega_0$ and $\omega$. Calculate $\omega_0/\omega$ for the collision. Compare it to your prediction and calculate the percent error. Show all your work below.