Conservation of Angular Momentum with a 3D-Printed Launcher

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Student difficulties in understanding the angular momentum of particles have been documented.[1] Examples involving a child jumping on or off a merry-go-round are often used to illustrate a particle's angular momentum. Analogous experiments have been suggested in which a ball collides completely inelastically[2,3] with a catcher on the arm of a rotational apparatus or is launched[4] from the arm. Although these experiments were done with homemade apparatuses, the collision experiment can now be performed with Pasco's projectile launcher, low-friction rotating platform, and some accessories.[5] A catcher[6] was previously available for purchase from Pasco, but they have now made an STL file for a 3D-printed version available online.[7] We describe how to perform the other experiment, where a ball is fired from the beam, using the same rotating platform and a launcher based on a 3D-printed part.[8]

The launcher that we designed is shown in figure 1, where the blue base is 3-D printed. It is attached to the T-shaped slot on the beam of Pasco's rotating platform by two 3/4"-long, 1/4-20 bolts with thumb screw knobs[9] and 1/4-20 square nuts. A horizontal, partially-threaded post [10] is attached to the base with nuts and washers. A spring[11] around the post is held in place by unwinding one end, pushing it through a small hole in the base, and bending it over. The projectile is a 1-inch diameter brass ball[12] with a 0.175" hole drilled through its center. The ball is slid onto the post compressing the spring, and it is held in place by a strong string[13] which is pinned down by a thumb screw [14] on each side. Notches were added to the post and ball to help keep the string from sliding off the ball. After the ball is loaded on the launcher, the string is burned to launch the ball with everything initially at rest. Since angular momentum is conserved, the angular momenta of the ball should be the same size as that of the beam and the launcher, but in the opposite direction.

Before performing the conservation of angular momentum experiment, the moment of inertia of the "beam" (really the beam and the shaft) is determined as described by Carr et al.[15] They cover the theory and analysis very well, so we don't repeat those here. The apparatus in reference 4 had the launcher permanently attached, so data was taken with it in place when determining the moment of inertia. Instead, we have our students take data to find the moment of inertia of the apparatus without the launcher, I_{beam}, then calculate the total moment of inertia after the ball is fired using

$$I \approx I_{\text{beam}} + m_{\text{launcher}} r_{\text{launcher}}^2, \tag{1}$$

where m_{launcher} and r_{launcher} are the launcher's mass and the radial position of its center, respectively. This reinforces how moments of inertia combine for a compound system, and it is more convenient when students perform additional experiments with the same apparatus. The angular speed ω just after the ball is launched is found from a linear fit to angular position vs. time data. The angular momentum associated with the rotation of the beam and launcher is

$$L_{rot} = I\omega. \tag{2}$$

The speed of the ball is determined by measuring the intial height h of the ball and the distance d that it travels horizontally. Since the ball is initially moving horizontally, its initial speed is

$$v = d\sqrt{g/2h}. \tag{3}$$

The ball is lauched perpendicular to the beam, so its angular momentum about the axis is

$$L_{\text{ball}} = m_{\text{ball}} r_{\text{ball}} v, \tag{4}$$

where m_{ball} and r_{ball} are the ball's mass and the radius from which it launches, respectively. (For our apparatus, $r_{\text{ball}} = r_{\text{launcher}}$ because the ball is centered on the launcher.)

This conservation of angular momentum experiment has been successfully performed in our calculus-based, introductory physics laboratory. It takes considerable force to compress the springs when loading the launcher, so some students required assistance. Our students have observed conservation of angular momentum to within a few percent. The experiment compliments other angular-momentum experiments that our students perform with the apparatus and provides them with experience with determining a compound system's moment of inertia and a particle's angular momentum.

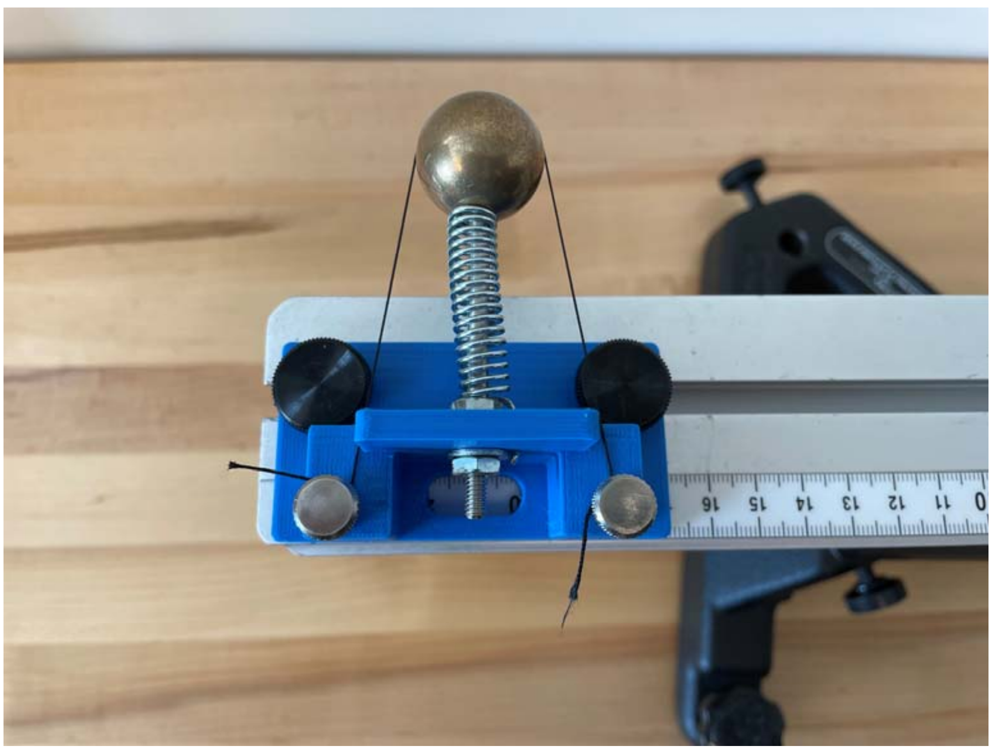

Fig. 1. The launcher loaded with a ball and ready to fire.

Endnotes

1. Hunter G. Close and Paula R. L. Heron, "Student understanding of the angular momentum of classical particles," *Am. J. Phys.* **79** (10), 1068-1078 (2011).
2. J. N. Palmieri and Karl Strauch, "An Experiment on Angular Momentum for the Introductory Laboratory," *Am. J. Phys.* **31** (2), 91-95 (1963).
3. Ken Altshuler and Peter Pollock, "Inexpensive Rotating-Arm Device for Angular-Motion Labs," *Phys. Teach.* **36** (7), 424-425 (1998).
4. R. Ö. Akyüz, "Angular momentum conservation (a freshman experiment)," *Am. J. Phys.* **64** (4), 446-448 (1996).
5. Pasco, Projectile Launcher (ME-6800), Rotating Platform (ME-8951), Super Pulley with Mounting Rod (ME-9499), and Photogate Head (ME-9498A).
6. Pasco, Projectile Collision Accessory (ME-6815) – no longer available.
7. "Ball Catcher for Rotation," <https://www.pasco.com/resources/diy/202>, accessed Jan. 4, 2023.
8. An STL file is available at https://www.thingiverse.com/thing:5793730.
9. Shear-Loc, 1/4" x 3/4" Knurled Black Knob (83-98-903B).
10. McMaster-Carr, 18-8 Stainless Steel Partially Threaded Stud, 8-32 Thread Size, 3" Long (97042A155).
11. McMaster-Carr, Compression Spring, 2" Long, 0.375" OD, 0.281" ID (9657K123).
12. GSC Go Science Crazy, 1-inch diameter brass balls. (42015-10)
13. Sargent Welch, Black Nylon Cord (CP-88066-00), which doesn't stretch much.
14. McMaster-Carr, Stainless Steel Flared-Collar Knurled-Head Thumb Screw, 8-32 Thread Size, 1/4" Long (99607A221).
15. Robert Carr, Harold Cohen, and Terry Ragsdale, "Demonstrating Angular Momentum Conservation," *Phys. Teach.* **48** (3), 169-171 (1999).