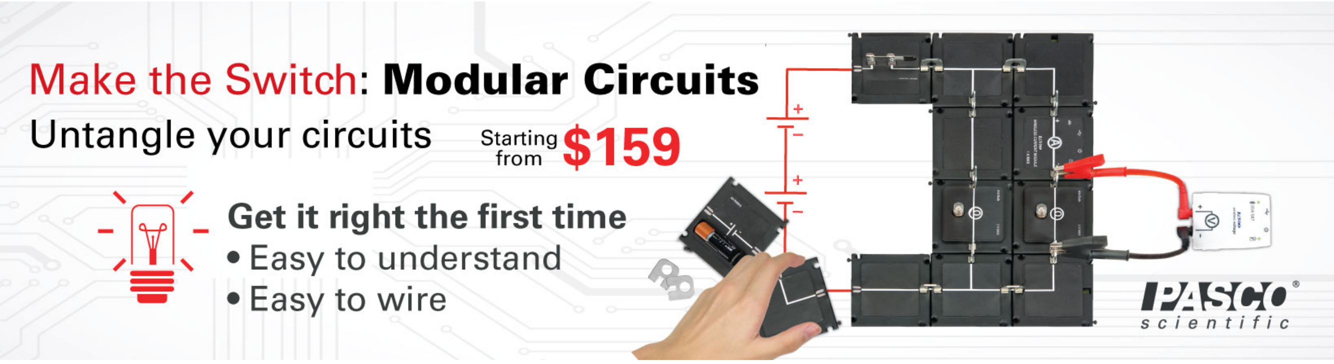
Angular momentum

Asif Shakur, and Taylor Sinatra

Citation: The Physics Teacher **51**, 564 (2013); doi: 10.1119/1.4830076
View online: http://dx.doi.org/10.1119/1.4830076
View Table of Contents: http://aapt.scitation.org/toc/pte/51/9
Published by the American Association of Physics Teachers



Jochen Kuhn and Patrik Vogt, **Column Editors**
University of Kaiserslautern, Kaiserslautern, Germany, and
University of Education Freiburg, Germany; kuhn@physik.uni-kl.de

Angular momentum

Asif Shakur and Taylor Sinatra, Salisbury University, Salisbury, MD 21801; AMSHAKUR@salisbury.edu

The gyroscope in a smartphone was employed in a physics laboratory setting to verify the conservation of angular momentum and the nonconservation of rotational kinetic energy. As is well-known, smartphones are ubiquitous on college campuses. These devices have a panoply of built-in sensors. This creates a unique opportunity for a new paradigm in the physics laboratory.[1-3] Many traditional physics experiments can now be performed very conveniently in a pedagogically enlightening environment while simultaneously reducing the laboratory budget substantially by using student-owned smartphones.

Experimental procedure

A "lazy Susan" turntable was acquired very cost-effectively[4] and used as a rotating platform. A smartphone was secured to the edge of the turntable by means of masking tape (Fig. 1). The "record" button on the app, xSensor by Crossbow Technology Inc.,[5] was pressed and the turntable was manually spun subsequently and almost simultaneously. The time delay does not have a deleterious effect on the integrity of the measurements, as the following discussion will convince the reader. The gyroscope output from the smartphone was recorded by the app for five seconds.

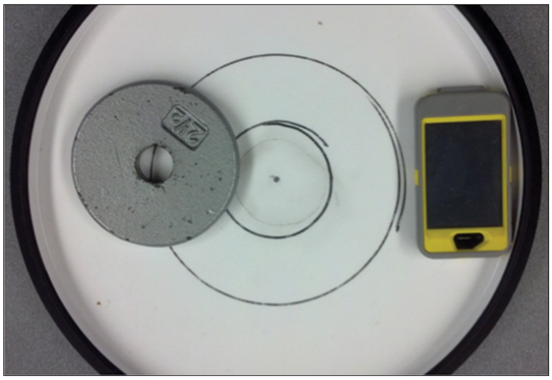


Fig. 1. Smartphone secured on a "lazy Susan" turntable.

This provided us the "control" data for the normal deceleration of the angular velocity, ω_z rad/s (gyroscope output of the smartphone), of the manually spun turntable. The weight was a 2.5-lb (1.13-kg) disk. The next step was to spin the turntable manually and gently drop the weight onto the spinning turntable. The experiment was repeated for three different positions where the weight was dropped. The gyroscope app on the smartphone dutifully recorded the angular velocity every 0.25 seconds. These data were analyzed to establish the conservation of angular momentum and the nonconservation of rotational kinetic energy.

Table I. Gyroscope data for disk drop at three different distances on the lazy Susan.

	ω_i	ω_f	$I_i\,\omega_i$	$I_f\,\omega_f$	$\frac{1}{2}I_i\,\omega_i^2$	$\frac{1}{2}I_f\,\omega_f^2$
r = 0 cm	11.9	10.1	0.199	0.193	1.19	0.98
r = 5 cm	11.5	8.8	0.192	0.193	1.1	0.85
r = 10 cm	11.1	6.18	0.186	0.188	1.03	0.58

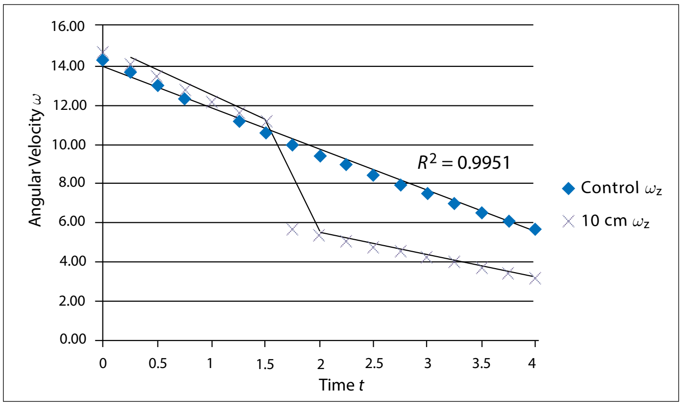


Fig. 2. Angular velocity vs time for the 1.13-kg weight drop.

Experimental data

The gyroscope data for the 1.13-kg weight drop for three different positions of the drop (r = 0 cm, r = 5 cm, and r = 10 cm) are recorded in Table I. The control data and one set of data for the 10-cm disk drop are depicted in Fig. 2.

Experiment meets theory

We will analyze the tabulated data and perform a sample calculation. But first let us get a few preliminaries out of the way. The lazy Susan has a mass of 415 g with a radius of 20 cm. This includes a black outer ring. The moment of inertia of the lazy Susan is calculated to be 12.6×10^{-3} kg.m^2. The moment of inertia of the smartphone with case was calculated to be 4.1×10^{-3} kg.m^2. Thus the total moment of inertia of the lazy Susan and smartphone combo is 16.7×10^{-3} kg.m^2. The 1.13-kg disk weight has a radius of 6.5 cm. We used the parallel-axis theorem to calculate the moment of inertia of the disk weight to be 2.4×10^{-3} kg.m^2 when dropped at the 0-cm mark (center of lazy Susan), 5.2×10^{-3} kg.m^2 when dropped at the 5-cm mark, and at the 10-cm mark to be 13.7×10^{-3} kg.m^2. In Fig. 2 for the 1.13-kg disk weight drop at the 10-cm mark, we note a sudden drop in the angular velocity from 11.11 rad/s to 5.68 rad/s. Incorporating the control correction of 0.5 rad/s (which is how much the lazy Susan would have decelerated even without the weight drop), we reckon that the weight drop slowed the lazy Susan from 11.11 rad/s to 6.18 rad/s. The angular momentum before the weight drop is $I_i\,\omega_i = (16.7 \times 10^{-3})(11.11)$, so $I_i\omega_i = 0.186$. The angular momentum after the weight drop is $I_f\,\omega_f = (30.4 \times 10^{-3})\,(6.18)$, so $I_f\,\omega_f = 0.188$. So the angular momentum is conserved to within 1%.

DOI: 10.1119/1.4830076

Is the rotational kinetic energy conserved?

We have established in the previous section that the angular momentum is conserved when we drop a weight onto a rotating platform. Let us consider the initial and final rotational kinetic energies for the same data from the gyroscope of the smartphone. In Fig. 2 for the 1.13-kg disk weight drop at the 10-cm mark, we note a sudden drop in the angular velocity from 11.11 rad/s to 5.68 rad/s. Incorporating the control correction of 0.5 rad/s (which is how much the lazy Susan would have decelerated even without the weight drop), we reckon that the weight drop slowed the lazy Susan from 11.11 rad/s to 6.18 rad/s. The rotational kinetic energy before the weight drop is $\frac{1}{2} I_i \, \omega_i^2 = \frac{1}{2} (16.7 \times 10^{-3}) (11.11)^2$, so $\frac{1}{2} I_i \, \omega_i^2 =$ 1.03 J. The rotational kinetic energy after the weight drop is $\frac{1}{2} I_f \, \omega_f^2 = \frac{1}{2} (30.4 \times 10^{-3}) (6.18)^2$, so $\frac{1}{2} I_f \, \omega_f^2 = 0.581$ J. So there is a 44% loss in the rotational kinetic energy.

Conclusion

We used the output of a smartphone gyroscope to establish the conservation of angular momentum in an experiment where a weight was dropped onto a rotating platform. In the same experiment, we demonstrated that the rotational kinetic energy is *not* conserved. The smartphone is a robust and versatile device that can accurately, conveniently, and reproducibly measure physical quantities such as magnetic fields, acceleration, and angular velocity. This creates an opportunity for a new paradigm in physics pedagogy. Student-owned smartphones can conveniently be implemented in the physics laboratory while reducing the laboratory budget. We have found that students take enormous pride in the data generated by their smartphones and are excited and motivated to learn from them. We even let them take their newfound physics toy home with them!

Acknowledgments

Taylor Sinatra, a very recent physics graduate of Salisbury University, was financially supported by the physics department. Both authors would like to express their indebtedness to Andrew Pica, chair of the physics department, for his support and encouragement.

References

1. P. Vogt and J. Kuhn, "Analyzing free fall with a smartphone acceleration sensor," *Phys. Teach.* **50**, 182–183 (March 2012).
2. P. Vogt and J. Kuhn, "Analyzing simple pendulum phenomena with a smartphone acceleration sensor," *Phys. Teach.* **50**, 439–440 (Oct. 2012).
3. P. Vogt and J. Kuhn, "Analyzing radial acceleration with a smartphone acceleration sensor," *Phys. Teach.* **51**, 182–183 (March 2013).
4. Oxo Good Grips "lazy Susan" turntable for $17 on Amazon.
5. We have a special website dedicated to smartphone physics. All apps have been made available for download at http://smartphonephysics.com. Please feel free to contact Professor Shakur at amshakur@salisbury.edu if you require further assistance.