Revisiting Riccioli's free-fall calculations

Christopher Graney provides a fascinating description of Giovanni Battista Riccioli's meticulous 17th-century experiments on free fall (PHYSICS TODAY, September 2012, page 36). He notes that Riccioli's results, converted to modern units, provide an estimate of g that is systematically 5% smaller than the current accepted value. The discrepancy might well be attributed to uncertainty over the modern equivalent of Riccioli's unit of length, the Roman foot. However, one more insight can perhaps be wrung from the data.

As Christiaan Huygens reported in his classic 1673 *Horologium Oscillatorium*, published 22 years after Riccioli's *Almagestum*, the period of a pendulum of length l is $T = 2\pi\sqrt{l/g}$. Thereafter it is an easy exercise to show that a plot of the distance fallen versus the square of the fall time in units of the pendulum half-period $T/2$ is a straight line of slope $\pi^2 l/2$. That figure is independent of g and of the conversion to modern units.

Plotting Riccioli's data in that way reveals an accurate straight line from which one can deduce the pendulum length. The answer—with a generous error estimate—is $l = 1.00 \pm 0.05$ Roman inches. As Graney notes, Riccioli himself reported the length to the center of the pendulum bob to be 1.15 inches. The 15% discrepancy—less than 4 mm—is plausibly excusable, though one might infer that Riccioli supposed his measurement was accurate to at least 0.05 inches (about 1 mm).

Unfortunately, the discrepancy is in the wrong direction to be attributed either to the distinction between the center of mass and the center of oscillation of a compound pendulum or to the fact, known to Riccioli, that large-amplitude pendulum swings are not quite isochronous. Nevertheless, the discrepancy is intrinsic to Riccioli's presented data and is not dependent on the disputed length of the Roman foot. One can only presume it reflects on the difficulty of subdividing a Roman foot into such fine equispaced divisions.

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Letters and commentary are encouraged and should be sent by email to ptletters@aip.org (using your surname as the Subject line), or by standard mail to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3842. Please include your name, work affiliation, mailing address, email address, and daytime phone number on your letter and attachments. You can also contact us online at http://contact.physicstoday.org. We reserve the right to edit submissions.

■ **The article by** Christopher Graney about the free-fall experiments of Giovanni Battista Riccioli opens a fascinating window on the work of one of the first modern physicists and his approach to devising a standard clock, finding its limitations, and using it to better determine fundamental laws of nature.

Not much has changed in the clock business since 1651. Unfortunately, the data on a falling clay ball, taken in painstaking detail by Riccioli and coworkers, is slightly misrepresented in Graney's figure 5. The time axis should be in units of seconds, not in pendulum strokes as stated. If taken seriously, the graph conveys that the ball would have fallen more than 250 Roman feet (about 75 m) in 4.5 strokes of the pendulum, less than 1 second (1 second corresponds to roughly 6 strokes of Riccioli's pendulum).

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■ **Graney replies:** Patrick Warren and Dietrich Leibfried raise interesting points about errors—both in Giovanni Battista Riccioli's work and, unfortunately, in my article. In the latter case, Leibfried is certainly correct about the units on the axis. In fact, other PHYSICS TODAY readers have called my attention to a number of typographical errors re-

lated to the plot and measurement values listed in the article. For example, the height of the Asinelli Tower according to Eleonora Bertacchini and coworkers (reference 15 in the article) is 97.38 m,[1] but in the article it is listed as 98.37 m. For typo-free (hopefully) plots and values, I refer readers to a full translation of Riccioli's report on falling bodies.[2]

No doubt Riccioli would understand all this. His *Almagestum novum* suffered from severe typos in places. For example, values labeled as being the radii of objects sometimes actually provided the diameters!

References

1. E. Bertacchini, E. Boni, A. Capra, C. Castagnetti, M. Dubbini, "Terrestrial Laser Scanner for Surveying and Monitoring Middle Age Towers," presented at the 24th FIG International Congress, 11–16 April 2010. Available at http://www.fig.net/pub/fig2010/ppt/ts04d/ts04d_capra_bertacchini_et_al_ppt_4445.pdf.
2. C. M. Graney, http://arxiv.org/abs/1204.3267.

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Online Friedmann resource

Ari Belenkiy's article (PHYSICS TODAY, October 2012, page 38) was thoroughly enjoyable. In it, Alexander Friedmann's 1922 publication on the expanding universe is identified as the origin of modern cosmology. That comment motivated me to look again into the papers Paul Ehrenfest left here in Leiden, papers that were discovered a few years back. They include a draft of Friedmann's 1922 paper, which was only published in German, and an earlier unpublished manuscript titled "On the question of the geometry of curved space." An accompanying letter to his friend Ehrenfest clearly shows that Friedmann knew he was onto something big with his discovery that "there appears also a world, the space of which possesses a curvature radius varying with time." I have placed the papers online at http://www.lorentz.leidenuniv.nl/history/Friedmann_archive as a tribute to this pioneer.

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