LETTERS TO THE EDITOR

The downloaded PDF for any Letter in this section contains all the Letters in this section.

Letters are selected for their expected interest for our readers. Some letters are sent to reviewers for advice; some are accepted or declined by the editor without review. Letters must be brief and may be edited, subject to the author’s approval of significant changes. Although some comments on published articles and notes may be appropriate as letters, most such comments are reviewed according to a special procedure and appear, if accepted, in the Notes and Discussions section. (See the “Statement of Editorial Policy” at http://www.aapt.org/ajp/docs/edpolicy.html.) Running controversies among letter writers will not be published.

SILVERED PING-PONG BALL BOUNCING UP AND DOWN INSIDE A CAPACITOR

In the August issue of this journal, Rezaeizadeh and Mameghani (hereafter R&M) analyze the motion of an aluminum pendulum bob swinging inside a vertically oriented parallel-plate capacitor, alternately being attracted to and repelled from each plate as it picks up positive and then negative charges.1 A similar demonstration uses two horizontal aluminum disks connected across a Van de Graaff generator. A ping-pong ball coated with silver paint is carefully tossed between the large-diameter circular plates. (The ball needs to enter nearly vertically so that it does not escape sideways, and with a large enough speed that it bounces back up to the top plate.)

In our apparatus, the two plates are held apart by a distance of \( x = 127 \text{ mm} \) using a small-diameter plastic cylinder. (The lower plate similarly rests on a cylinder, so that both plates ring loudly when impacted by the bouncing ball.)

The painted ball has mass \( m = 2.75 \text{ g} \) and radius \( r = 18.8 \text{ mm} \). The coefficient of restitution (COR) is found to be \( \varepsilon = 0.78 \) by dropping the ball from several heights onto the top plate and measuring the rebound heights. A Winsco model N100-V Van de Graaff generator produces a potential difference of \( V \approx 90 \text{ kV} \) while the capacitor is connected, estimated by noting that sparks can jump 3 cm from the top dome to a grounded sphere brought near it and given that the dielectric breakdown strength of air is \( 3 \text{ kV/mm} \). The resistance of the silvered ball averaged across various diameters is \( 2 \Omega \), implying good conductivity. When the ball comes into contact with a plate, their surface charge densities become nearly equal,\(^2\) so that the ball acquires a charge of magnitude \( q = 4\pi\varepsilon_0 r^2 V/x \), where \( \varepsilon_0 = 8.85 \text{ pF/m} \) is the permittivity of free space.

Let us denote kinematic quantities with a prime when the ball is traveling downward and without a prime when moving upward. The acceleration of the downward-moving ball has magnitude \( a' = g + qE/m \), where \( E = V/x \) is the magnitude of the electric field inside the capacitor and \( g = 9.8 \text{ m/s}^2 \). On the other hand, the ball decelerates as it rises because gravity pulls downward more strongly than the electric field pushes the ball up, consistent with the observation that the ball needs to be initially launched downward with a significant speed if it is to commence a repeated bounce pattern. (If the ball is placed on the lower plate, it tends to roll but it does not levitate.) Thus the magnitude of the acceleration of the upward-moving ball is \( a = g - qE/m \).

The steady-state analysis of R&M can now be applied to find that the time it takes the ball to travel up from the bottom to the top plate is

\[
\Delta t = \sqrt{\frac{2x}{1 - \varepsilon^2}} \frac{\varepsilon \sqrt{a' - \varepsilon a'^2} - \sqrt{a'v^2 - a}}{a}.
\]

Similarly, the time to travel down from the top to the bottom plate is

\[
\Delta t' = \sqrt{\frac{2x}{1 - \varepsilon^2}} \frac{\varepsilon \sqrt{a' - \varepsilon a'^2} - \sqrt{a'v^2 - a}}{a'}.
\]

The necessary and sufficient condition for these two times to be real and positive is that \( \varepsilon^2 > a/a' \), which is satisfied for the numerical values given above. In fact, our value of \( \varepsilon \) is large enough that both Eqs. (1) and (2) can be accurately approximated by

\[
\Delta t \approx \Delta t' \approx \sqrt{\frac{m(1 - \varepsilon)}{2\pi\varepsilon_0 r^2(1 + \varepsilon)}} x^{3/2} V^{-1},
\]

which reproduces R&M’s Eq. (11). If the COR is near unity, the ball picks up enough speed after a few bounces that gravity can subsequently be neglected. Figure 2 of Ref. 1 verifies this \( x^{3/2} \) dependence of \( \Delta t \), while the graphs in Ref. 4 confirm the \( V^{-1} \) variation. For our apparatus, Eq. (3) predicts a time between plate collisions of 66 ms.

To compare to experiment, the sound of the bouncing ball can be recorded with a microphone connected to a computer, and the time intervals between the start of each plate’s ringing measured, using the freeware program Audacity.\(^5\) As Eq. (3) suggests, no noticeable difference is found between upward and downward times within the roughly 5% jitter observed experimentally for the ball’s motion. The average time interval is 69 ms, in agreement with the prediction.\(^6\) As others have suggested,\(^7\) the accuracy is sufficient to contemplate developing a physics lab based on these ideas. (The Van de Graaff can be replaced with a calibrated few hundred volt dc supply by using both a smaller ball and plate spacing.)


\(^3\)Quadratic air resistance has magnitude \( C \rho \pi r^2 v^2/2 \), where the drag coefficient for a sphere is \( C = 0.5 \) and the density of air at room temperature is \( \rho = 1.2 \text{ kg/m}^3 \). Even at the ball’s
maximum speed of \( u = 1.9 \text{ m/s} \), the drag force is less than 5% of the gravitational force on the ball and can thus be neglected.


6If both gravity and quadratic air drag are retained in the model, the steady-state time intervals are calculated to be \( \Delta t = 71 \text{ ms} \) and \( \Delta t' = 68 \text{ ms} \).