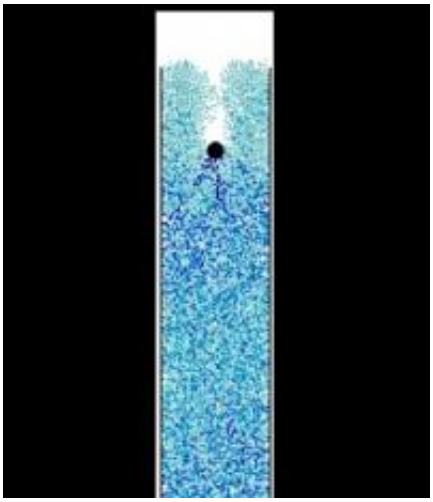
Weighted ping-pong balls can fall endlessly through a granular medium (w/ video)

June 27 2011, by Lisa Zyga



This partial image taken from the video below shows a projectile near the beginning of its trajectory as it falls through a tube filled with granular matter. Image credit: F. Pacheco-Vázquez, et al. ©2011 American Physical Society

(PhysOrg.com) -- When a meteor impacts a planet or a moon, it always stops at a relatively shallow depth, even when impacting at high speeds. Until now, researchers have assumed that all objects impacting a granular medium – such as sand or beads – rapidly lose energy and stop at a shallow depth. But in a new study, researchers have demonstrated that weighted ping-pong balls impacting a 600-cm (20-ft)-long tube filled with polystyrene beads can reach a terminal velocity, which allows the balls to continue sinking endlessly to an infinite depth.

The team of researchers, Felipe Pacheco-Vázquez, et al., from institutions in Mexico and Cuba, has published their study on the surprising result in a recent issue of Physical Review Letters. As the scientists explain, their study shows that some granular matter is "no longer safe to walk on."

"One may safely walk on sand, and also on sugar, rice, and a myriad of dry granular materials," Pacheco-Vázquez of CINVESTAV-Monterrey in Nuevo Leon, Mexico, told *PhysOrg.com*. "In this paper, we warn that not all such materials are safe to walk on. In fact, under certain conditions, one can be endlessly swallowed by the medium. We show that, when a spherical 'intruder' is deposited on the free surface of a silo of expanded polystyrene beads, it plunges into the 'granular sea,' eventually stopping at a certain depth or falling forever, depending on the weight of the intruder."

As the researchers explain in their study, the possibility of an object reaching a terminal velocity while sinking through a granular medium has never before been observed or predicted, although terminal velocity is well-documented for objects traveling through fluids. Researchers have assumed that all objects impacting a granular medium should eventually come to a stop due to the inelastic properties of granular materials (i.e., the grains do not easily move under an applied stress). In contrast, an object falling in a fluid can reach a terminal velocity because molecules in a fluid move much more easily under an applied stress.

Here, the researchers performed several experiments in which they launched 4-cm-diameter ping-pong balls into a long cardboard tube, which had an inner diameter of 45 cm and was filled with polystyrene beads. Each of the ping-pong balls had a small hole through which the researchers could add steel particles to obtain a desired mass, and then seal the hole. The researchers prepared 18 ping-pong balls with masses ranging from 15 to 182 g. Using a launching pad above the tube, the

researchers released the ping-pong balls and tracked their trajectories with a high-speed video camera and a wireless accelerometer as they fell through the tube.

The results showed that the lighter ping-pong balls slowed down and stopped in the middle of the tube, while ping-pong balls with masses greater than about 86 g sank all the way to the bottom. Further, the velocities of the balls that reached the bottom seemed to level off, suggesting that they had reached a constant velocity.

Through calculations and simulations, the researchers showed that, if the length of the tube were extended, the heavier balls would continue to sink indefinitely. The reason is that the balls reached a terminal velocity when the upward drag force and the downward force of gravity (which depends on the object's mass) were balanced. At this time, the object's acceleration is zero, so that it continues sinking at a constant speed.

From a physics perspective, the only way for an object to achieve terminal velocity in a granular medium is if the depth-dependent force of friction felt by the sinking object becomes saturated (constant) before it matches the gravitational force dependent on the object's weight. Although this reasoning sounds logical, the researchers explain that it goes against intuition, since one would expect the projectile to be stopped due to its high energy dissipation with the grains.

The researchers noted that the two conditions needed for an object to reach a terminal velocity are a critical mass and a complete saturation of the object's initial pressure. This finding implies that, even if an object has an extremely high initial velocity, it won't achieve terminal velocity if it does not have the critical mass. So even for a bullet shot from a gun, if the bullet's mass is less than the critical value, it will eventually come to a stop.

On a final note, the researchers emphasized that the critical mass differs for different granular media due to the different densities of the media. For example, for a ping-pong-ball-sized object to achieve a terminal velocity when impacting sand, the object would have to have a mass of about 14 kg (for a density of 400 g/cm3). No known material on Earth has such a large density.

In the future, the scientists plan to investigate what happens when several objects impact a granular medium simultaneously.

“We would like to study the penetration of a group of projectiles with a mass greater than the critical mass in this particular medium, because maybe we can observe an infinite cooperative dynamics,” Pacheco-Vázquez said. The scientists have previously investigated similar cooperative dynamics in an earlier study.

More information: F. Pacheco-Vázquez, et al. “Infinite Penetration of a Projectile into a Granular Medium.” *Physical Review Letters* 106, 218001 (2011). DOI:10.1103/PhysRevLett.106.218001