

# PRELIMINARY EXPERIMENTS DEMONSTRATING A CONTROLLABLE GRANULAR DEMON

## EXPERIMENTOS PRELIMINARES QUE DEMUESTRAN UN DEMONIO GRANULAR CONTROLABLE

F. CORRALES<sup>a</sup>, Y. NAHMAD<sup>b</sup>, E. ALTSHULER<sup>a†</sup>

a) Group of Complex Systems and Statistical Physics, University of Havana, 10400 La Habana, Cuba; ealtshuler@fisica.uh.cu<sup>†</sup>

b) Instituto de Física, Zona Universitaria San Luis Potosí, SLP 78290, México.

† corresponding author

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In this paper, we design a system of two symmetrical containers communicated by an aperture, in which a granular gas of glass spheres is created by shaking laterally the whole system in a planetary mill. If the aperture consists in a symmetrical hole, the two halves end up with the same number of grains after some time when initially all particles are into in one of the containers. However, when a funnel-like aperture is used, a robust symmetry breaking is induced: if all the grains are originally deposited in the container facing the wide side 95 % of the grains pass to the opposite side in a relatively small time.

En este trabajo, diseñamos un sistema de dos contenedores simétricos comunicados por una apertura, en el que se crea un gas granular de esferas de vidrio agitando lateralmente todo el sistema en un molino planetario. Si la apertura consiste en un agujero simétrico, las dos mitades terminan con el mismo número de granos después de un tiempo, si inicialmente todas las partículas están dentro de uno de los contenedores. Sin embargo, cuando se usa una abertura en forma de embudo, se induce una ruptura de simetría robusta: si todos los granos están originalmente depositados en el recipiente que mira hacia el lado ancho, 95 % de los granos pasan al lado opuesto en un tiempo relativamente pequeño.

PACS: Maxwell-like demon (Demonio tipo Maxwell), 36.40.Ei; granular gases (gases granulares), 45.70.-n; mechanical vibrations (vibraciones mecánicas), 46.40.-f; symmetry breaking (ruptura de simetría), 11.30.Qc

### I. INTRODUCTION

Granular matter in motion is known to display many unexpected behaviors: “Brazil-nuts” effects [1] and wave patterns [2] in vibrated grains; ticking sand in hourglasses [3], avalanches and uphill solitary waves in granular flows [4, 5], “revolving rivers” in conical sandpiles [6], gravity-independent penetration of intruders in granular beds [7] and many others [8].

We concentrate here on one of the most puzzling granular phenomena: dense versus dilute phase separation into indistinguishable and equivalent communicated compartments, spontaneously occurs in vibrated granular systems.

It was first observed by Schlichting and Nordmeier in 1996 [9] and then approached experimentally or theoretically by others [10–15]. Such effects have been generically called *granular Maxwell demons*. One of their common features is the *spontaneity* of the specific direction of the symmetry breaking; the formation of the cluster takes place randomly either in the left or in the right containers.

It is worth mentioning that symmetry breaking phenomena in granular matter is not exclusive of the so-called “Maxwell demons”. For example, in quasi two-dimensional granular systems subjected to vertical vibrations, a phase transition

from a crystalline array of particles to a granular gas is observed [16].

In granular demons, the symmetry breaking is believed to occur due to the dissipative collisions between grains. Thanks to that, if a set of colliding particles locally decreases the gas “temperature” (*i.e.*, the average kinetic energy of the particles), new grains collide with those and cool down, resulting in the amplification of the fluctuation: a large cluster (or clusters) [14, 17] can be eventually formed into one of the connected containers, then breaking the symmetry.

The grains thus act as Maxwell’s demon, who preferentially lets particles pass from left to right or vice versa. As a result, a more ordered state is formed in which most particles are on one side. The demon must then absorb entropy, a role which in our system is assumed by the sand grains. Still another interpretation would be that of a dissipative structure, which in the stationary state is maintained by a flux of entropy.

In this paper, we offer an alternative of the classical granular Maxwell-demon: by using a funnel-like geometry of the aperture between the two spaces containing a granular gas, we promote a symmetry breaking in their densities even under the same experimental conditions where it does not arise using a conventional, symmetric aperture. Moreover, we are able to control in what direction the symmetry will be broken.

## II. MATERIALS AND METHODS

Our experimental setup consists in a cubic container of 10 cm-side divided into two equal volumes by a vertical wall along the diagonal direction as shown in Fig. 1(a). The two volumes are communicated by a funnel-like channel of 14 mm height, with large and small holes of diameters 21 and 4 mm, respectively, as shown in Fig. 1(c). Two cubical boxes like that are mounted into a planetary mill, describing the motion sketched in Fig. 1(b).

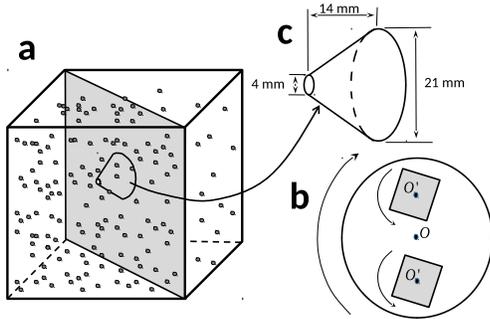


Figure 1. The experimental setup. (a) Glass cube split into two equal spaces using a funnel-like aperture. The small particles are 2 mm diameter glass beads. (b) Top view of the planetary shaker where two gas containers are simultaneously studied (The main platform revolves clockwise around the vertical axis  $O$  at 1 Hz, while each container revolves counterclockwise around  $O'$  at 0.75 Hz). The curved arrows indicate the rotational motion of the different parts of the device. (c) Details of the funnel-like channel.

As a result, the system experiences a strong agitation. In a typical experiment, 10000 glass beads (each one with a mass

of 0.01 g) are introduced into the volume corresponding to the wide side of the funnel aperture (Space 1 in Fig. 2). Due to the strong agitation, they behave like a granular gas. Fig. 2 shows snapshots taken from top, at different moments, where the total of 10000 grains initially occupied space 1.

In order to quantify in detail the temporal evolution of the particle distribution, we performed experiments where the planetary mill was turned off every few seconds after the beginning of the experiment, and the number of beads into the originally empty space was determined by weighting them. Then, the beads were put back and the agitation was re-started.

## III. RESULTS

The two upper curves in Fig. 3 show the temporal evolution of the number of glass beads in the half-container that was originally empty (each curve correspond to one of two identical boxed mounted on the planetary mill). As can be seen, nearly 95% of the beads have passed to the opposite space after 2000 seconds. The inset illustrates that, the time evolution approaches to  $N(t) = N_{tot}(1 - e^{-t/\tau})$ , where  $N_{tot}$  is the total amount of grains, and  $\tau$  is a constant fixed by the grain size, the wall aperture and the shaking parameters. The bottom curves correspond to a similar experiment, except for the fact that the 10000 beads have been originally situated in the container facing the small aperture of the funnel. As can be seen, only 5% of the beads have managed to pass to the opposite space, in good agreement with the previous experiment.

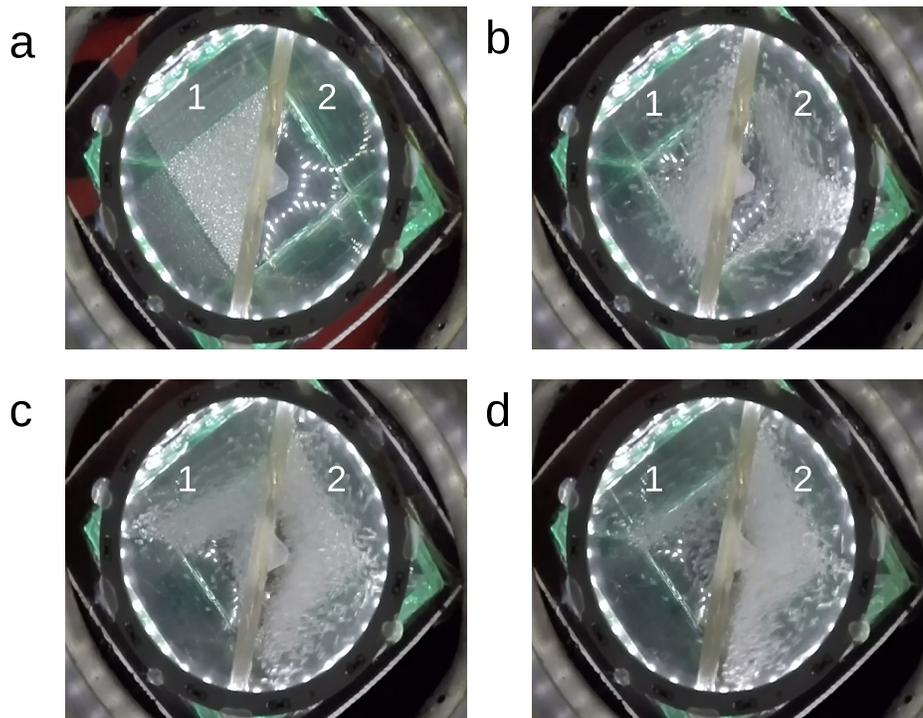


Figure 2. Directing a Maxwell-like granular demon. Snapshots taken from the top of one of the boxes at (a) before starting the experiment, and (b) 200, (c) 500 and (d) 3000 seconds after the beginning of the experiment, which started with a total of 10000 beads into semi-space 1. The bright spots are spurious reflections associated to the light emitting diodes used to illuminate the photographs.

Finally, the pair of curves shown in the middle of the graph correspond to an aperture consisting in a simple hole of 4 mm diameter. At the beginning of the experiment, the 10000 beads were deposited on one of the halves. After 6500 seconds (not shown in the graph of Fig. 3), the two half-spaces contain 50 % of the beads: the symmetry has not been broken. It is worth noting that, if this experiment is started with 50 % of the

beads into each half –i.e., the common practice in analogous experiments [9]– the final proportions are maintained, within small fluctuations. Moreover, the symmetry is not broken even for smaller agitation strengths, a somewhat unexpected result in the light of Egger’s model [10]. However, in view of the fact that our agitation is perpendicular to gravity, our output not necessarily contradicts Eggers ideas.

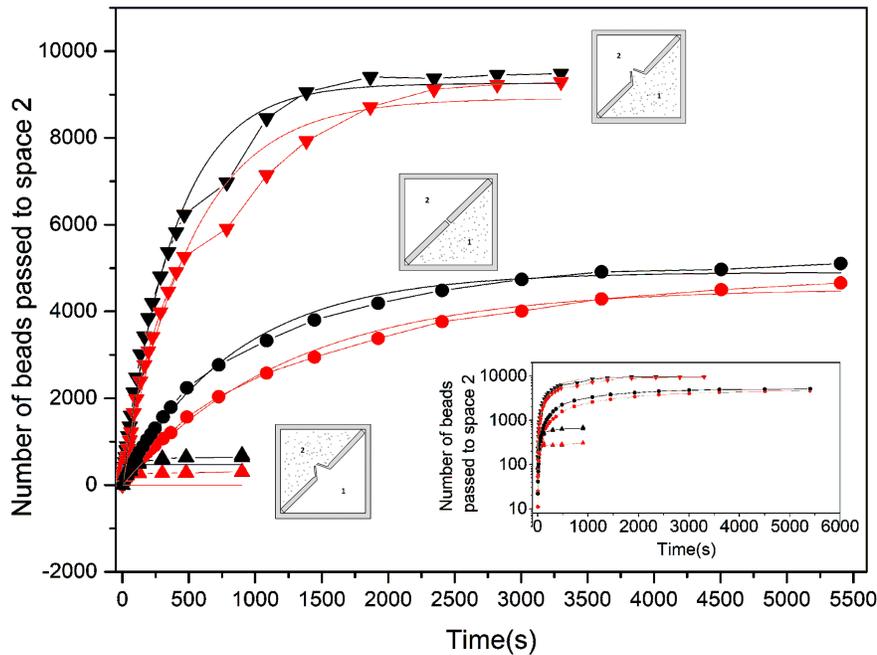


Figure 3. Time evolution of the number of particles passing to the opposite half-space for three different types of barriers. The curves correspond to the filling up of one half of the cube due to the passage of beads from the opposite side, that contained the 10 000 available beads at the beginning of the experiment. Every one of the three pairs of curves correspond to the initial conditions sketched near each of them. The pairs of curves for all cases are the results of two repetitions of each type of experiment. (Notice that the experimental situation illustrated in Fig. 2 is that corresponding to the two upper curves here). The inset shows the same curves, in semi-log scale for a larger time scale. The continuous lines represent a fit using an exponential law (see text).

#### IV. CONCLUSION

With the introduction of the funnel-like aperture we have “catalyzed” the Maxwell-like demon effect in a system where it does not appear using a symmetric connection between containers. We produce the effect even when the system starts from the opposite symmetry –i.e., the container initially full is emptied to fill up the opposite one. Our system is quite different from usual experiments, in the sense that the symmetry breaking action is triggered by a “selective” element (the funnel-like aperture), instead of depending on the random formation of clusters in *any* of the two symmetrical containers. The funnel also increases the evolution speed of the system: while the symmetry is reversed within 2000 seconds, the substitution of the funnel by a symmetrical hole takes more than twice as much time to reach the symmetric state (see Fig. 3, top and middle curves, respectively). Even when our aperture is very small compared to the separating wall (its area is just a 3 % of the total wall area), the presence of the funnel introduces a “ratchet effect” capable of changing the overall dynamics of

the granular system in a relatively small time. In fact, related effects have been observed at a microscopic scale in silicon membranes with asymmetric pores, when acting as “massive parallel brownian ratchets” [18], and in millimetric disks, as they diffuse through a membrane made of asymmetric pores [19].

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