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Bistable clustering in driven granular mixtures

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Abstract

The behavior of a bidisperse inelastic gas vertically shaken in a compartmentalized container is investigated using two different approaches: the first is a mean-field dynamical model, which treats the number of particles in the two compartments and the associated kinetic temperatures in a self-consistent fashion; the second is an event-driven numerical simulation. Both approaches reveal a non-stationary regime, which has no counterpart in the case of monodisperse granular gases. Specifically, when the mass difference between the two species exceeds a certain threshold the populations display a bistable behavior, with particles of each species switching back and forth between compartments. The reason for such an unexpected behavior is attributed to the interplay of kinetic energy non-equipartition due to inelasticity with the energy redistribution induced by collisions. The mean-field model and numerical simulation are found to agree qualitatively.

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1. Introduction

Granular fluids are currently attracting growing interests in view of their unusual properties, some of which are not fully understood yet. Moreover, new experiments continue to reveal unexpected phenomena, which have no counterpart in molecular fluids. Clustering, shear instability, non-Maxwellian velocity distributions, long-range velocity correlations, non-equipartition in a binary mixture are just a few of these peculiarities [1–3]. Recently, another fascinating phenomenon was reported. It is the so-called ‘‘Maxwell sand daemon’’ experiment [4], where a system consisting of inelastic particles enclosed in a two-compartment container is shaken vertically. Particles can flow from one compartment to the other through a small orifice located at a certain height from the basal vibrating plate. For strong shaking, the right and left populations are statistically equal, whereas for weak shaking the system spontaneously breaks the left–right symmetry. The mechanism behind such an unusual ordering process is the clustering induced by inelasticity.

In fact, an imbalance in populations induced by a fluctuation can be amplified, since it causes a larger energy dissipation on the overpopulated side, thus suppressing the outflow from that compartment. At the same time, inflow from the under-populated compartment is enhanced because of its lower occupation, which results in higher kinetic energies per particle [5].

Quite recently, the Twente collaboration [6] investigated the behavior of a bidisperse granular mixture of small and large particles using a similar experimental setup. Their experiments demonstrated that a bidisperse compartmentalized granular mixture has a tendency to cluster competitively. Depending on the shaking strength, one can observe different asymptotic configurations.

Theoretical treatments of granular gases in compartmentalized systems range from phenomenological flux models [5–12], to molecular dynamics [13,14], to more refined kinetic approaches [15]. Whereas the full solution of the inelastic Boltzmann equation remains a formidable task, a simple set of mean-field dynamical equations can be derived [16,17]. According to this method, the kinetic temperatures and the occupation numbers in each compartment are assumed to be the only relevant dynamical variables and treated on equal footing, a technique which naturally lends itself to capture the more complex phenomenology expected in mixtures.

Here we study a binary mixture of inelastic hard disks in a two-compartment system. The two species have different masses, are subjected to gravity and driven by a vibrating base. We extend the mean-field treatment of Ref. [16] and compare its predictions with the results of even-driven simulations.

The paper is organized as follows: after introducing our model in Section 2, we develop our mean-field treatment in Section 3. In Section 4 we report the predictions of our model and summarize our findings with a mean-field ‘‘phase diagram’’, where the boundaries between different regimes are studied as a function of the control parameters. In Section 5 we turn to the event-driven simulation and find qualitative agreement with the previous picture. Finally, in Section 6, we present our conclusions.