Ordering and dynamics in a thin vibrated granular layer

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We present in this work a review of past and recent advances on the granular dynamics of a thin granular layer that is vibrated vertically (in the presence of a gravitational field with acceleration $g = 9.8$ m/s^2). Since the work by the group at Texas Austin [1] and others, it has been shown that a granular layer vibrated vertically can display a number of patterns and cells. These phenomena can be understood and explained theoretically, in some cases, as a thermal convection, that has some peculiarities with respect to thermal convection in molecular fluids.

However, the granular layer, if sufficiently dense, can display ordering phenomena with an essentially different nature, as a series of experiments have shown. In Fig. 1 we can see a sketch of the experimental system. What we see now in this kind of confined system can be regarded as phase transitions instead. For instance, the granular layer can spontaneously come to an arrest state (from a previously disordered state) for a low enough vibration acceleration ($\Gamma \leq 1$) with a hexagonal symmetry in a variant of the sketch shown in Fig. 1, without the top lid. This kind of phase was shown two decades ago [2]. For the confined system depicted in Fig. 1, it was shown in experiments that a cubic symmetry phase can appear for a system with $h \sim 1.75\sigma$ [3]. Later on, the phase map was completed by means of molecular dynamics simulations [4], for a range of different values of the system width h and density, showing that the set of ordered phases that appear in the confined granular layer is essentially analogous to the phases observed in colloidal systems (particles with elastic collisions) [5].

And yet, contrary to what happens in colloids, these ordered phases may melt for sufficiently high acceleration input [6]. Moreover, the melting point depends dramatically of the degree of inelasticity in the collisions [6]. To the point that very inelastic collisions can completely suppress ordering in the whole phase map, in complete disagreement with classical results for equilibrium systems. No theoretical explanation has been conveyed for this fact so far. And additional experimental results have deepened later in the description of this important effect either.

We now focus on the role of inelasticity in the phase behavior of the thin vibrated granular layer, showing results specifically for the hexatic phase, that has already been observed in a granular system [7]. As it is known, the hexatic phase forms part of the description of the liquid to solid crystal transition as a continuous transition in molecular 2D materials. We analyze also the limits of the agreement and the aspects that depart from the KTHNY description of this phase transition [8, 9, 10], when dealing with a thin granular layer.

We will also review the results on this kind experimental setup reported by other groups. The reader may find a comprehensive review in the recent work by Mujica & Soto [11].

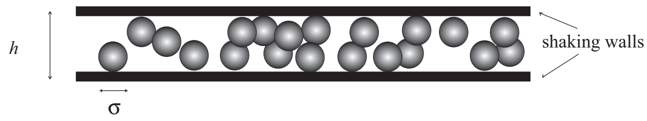

Fig. 1. We study a thin vibrated granular layer that is densely packed. The system width (distance between the two vibrating horizontal walls) is denoted as h and the particles diameter is σ (all particles are identical). The input acceleration $\Gamma \equiv A\omega^2/g$, where g is the gravitational acceleration. The vibration has sinusoidally-shaped, with amplitude A and angular frequency ω.

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