Ordering and defects in vibrated monolayers of granular rods

Ariel Díaz-De Armas[1], Martín Maza Cuello[2], Yuri Martínez-Ratón[1], and Enrique Velasco[2]
[1]Departamento de Matemáticas, Universidad Carlos III de Madrid, av. Universidad 30, E-28911 Leganés, Madrid, Spain
[2]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

The appearance of liquid-crystalline structures in 2D fluids of hard anisotropic particles provides a great opportunity for experimentation, aimed towards the study and understanding of liquid-crystal phases and phase transitions. The stability of these structures has been shown to be completely determined by entropy [1, 2]. Particles such as hard rectangles (HR) can be found on a completely unordered state referred to as the **I**sotropic phase, but also a **N**ematic phase where the main particle axis orientates on average along a common director. Unique to HR fluids is the **T**etratic phase where particles align along 2 different directors perpendicular to each other. Other oriented phases such as the **S**mectic phase, formed by layers perpendicular to the particles main axis, are also present. Monolayers of vertically shaken granular rods have been found to present similar liquid-crystal textures as stationary states [3, 4, 5]

Our work presents experiments conducted on a monolayer of granular cylindrical rods whose 2D projections are HR. The particles are vibrated in the vertical direction and they are not allowed to overlap, becoming in practice a 2D system. They are confined to a circular cavity (see Fig. 1 for the sketch of our experimental setup). Among the main lines of our study is that of understanding not only the effect of the shape of the cavity (circular vs. square) on the overall system behaviour but also the changes in the stable spatial patterns induced by the presence of a central obstacle of varying size.

By means of image analysis we are able to calculate local order parameters $Q_n(\mathbf{r})$ for each phase, defined from the angular distribution function of the local particle orientations $h(\phi, \mathbf{r})$, in the frame of the **N** director, as

$$Q_n(\mathbf{r}) = \int_0^{2\pi} d\phi \; h(\phi, \mathbf{r}) \cos(n\phi), \qquad (n = 2, 4), \qquad (1)$$

where ϕ is the angle between particle axis and the **N** director, $\mathbf{r}$ is the spatial coordinate and $Q_2(\mathbf{r})$ and $Q_4(\mathbf{r})$ correspond to the **N** and **T** local order parameters, respectively. At bulk the **T** phase has $Q_2 = 0$ while $Q_4 \neq 0$ due to the symmetry $h(\phi) = h(\phi + \frac{\pi}{2})$ while the **N** phase has both order parameters different from zero because of the symmetry $h(\phi) = h(\phi + \pi)$.

We have found the appearance of four punctual defects in the orientations of the nematic director following the **T** ordering. These defects have a total topological charge of 4 and are approximately located in the corners of a square as the system attempts to solve the frustration induced by the circular cavity. The introduction of the central obstacle has shown to favour the formation of **S** domains, which also present a high value of $Q_2(\mathbf{r})$, separated by blade-like interfaces (Fig. 2) and also pull the defects towards the middle, sometimes connecting the inner and outer walls through a line. We have also observed that the obstacle induces strong unidirectional rotation once a particular configuration stabilizes.

We have developed ways to track the evolution of defects and studied the impact of clustering in the stability of different phases.

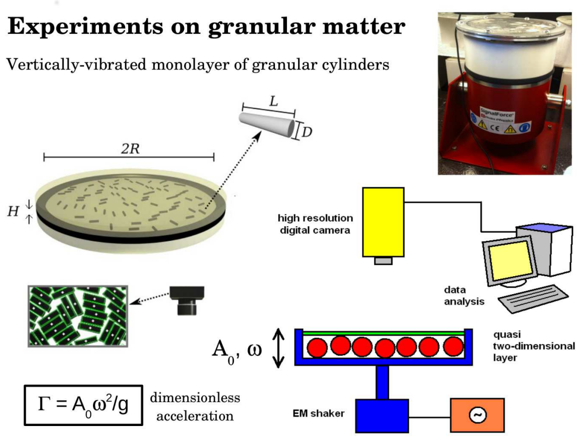

Fig. 1. Experiment concept and setup.

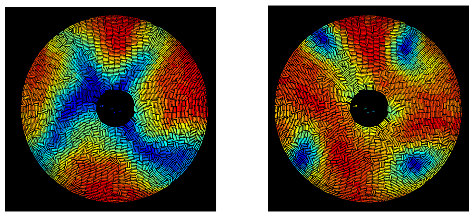

Fig. 2. Images of colored particles according to the values of the local order parameters (going from blue to red as Q_n goes from low to high values). Q_2 and Q_4 are shown left and right, respectively.

[1] M. A. Bates and D. Frenkel, J. Chem. Phys. **122**, 10034 (2000).

[2] Y. Martínez-Ratón, E. Velasco, and L. Mederos, J. Chem. Phys. **122**, 064903 (2005).

[3] V. Narayan, N. Menon, and S. Ramaswamy, J. Stat. Mech. **2006**, P01005 (2006).

[4] T. Müller, D. de las Heras, I. Rehberg, and K. Huang, Phys. Rev. E **91**, 062207 (2015).

[5] M. González-Pinto, F. Borondo, Y. Martínez-Ratón, and E. Velasco, Soft Matter, **13**, 2571 (2017).