Liquid-like dynamics in ordered soft-particle systems

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Structure most frequently constrains material behavior through the presence of a characteristic length scale that determines the properties of the system. This coupling is, in fact, a well-established paradigm in materials science [1], extending from atomic to colloidal systems. It is, in particular, reflected in the approach to the glass whereby strong spatial correlations between nearest-neighbor particles dominate the structural relaxation time of the material [2,3]. The relevance of colloids versus atoms lies in the fact that their interactions and single-particle softness can be tailored. This provides additional degrees of freedom that activate alternative relaxation pathways and even lead to a structural relaxation time that is independent of the strong short-range positional correlations between particles. As a result, structural and dynamics aspects become decoupled [4,5]. While these previous results indicate that elastic tailoring can manipulate dynamics properties independently of the structural ones, to date, this has been mostly explored in systems where each of the constituent particles has identical or very similar elastic properties.

Here, we explore the effects of elastic heterogeneity through numerical simulations of two-dimensional systems. Starting from a perfect triangular lattice, we introduce a broad range of particle elastic moduli, which enables the system to transition from a liquid to a crystalline state. Throughout this transition, the microscopic dynamics slow down, resembling those observed in glassy materials: structural relaxation becomes a two-step process, involving particles trapped in microscopic cages formed by their neighbors. Surprisingly, although strong elastic heterogeneity promotes long-range positional and orientational order, the presence of soft particles allows the system to remain dynamically active at long times, eventually reaching a diffusive regime. These findings stand in stark contrast to conventional crystals, where dynamics are typically restricted to vibrations, while translational degrees of freedom are suppressed as a result of the long-range order. Remarkably, the liquid-like dynamics we observe emerge while preserving the crystalline state, owing to swapping mechanisms in which particles exchange positions yet maintain the integrity of their local microscopic cages. As a result, elasticity polydispersity not only introduces translational degrees of freedom but also simultaneously stabilizes the crystalline structure. Our findings therefore blur the conventional distinction between solids and liquids, or between crystals and glasses, and highlight that elasticity polydispersity can decouple static and dynamic properties [6].

Keywords:
Elastic polydispersity, colloidal systems, swapping, structure-dynamics decoupling

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