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Cluster versus single-particle hopping in a colloidal model

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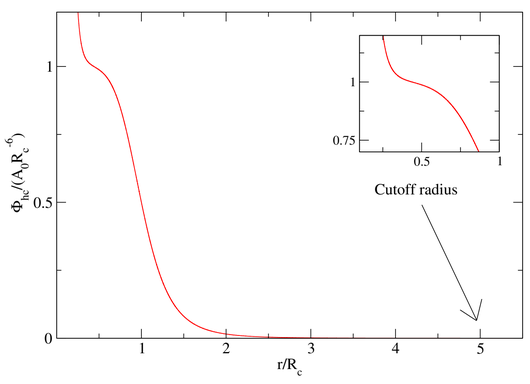
Summary

We present a study of a two-dimensional model for interacting colloids which is consistent with cluster states, adding a periodic corrugation potential and an external force. For dierent colloidal densities and different amplitude of the periodic corrugation potential we investigate the depinning from the static to the sliding regime. In the sliding states we characterize the competition between a dynamics where entire clusters are pulled from a minimum to the next and a dynamics where single colloids or smaller groups leave a cluster and move across the corrugation barrier to join the next cluster, as in the sequence of snapshots below.

The model

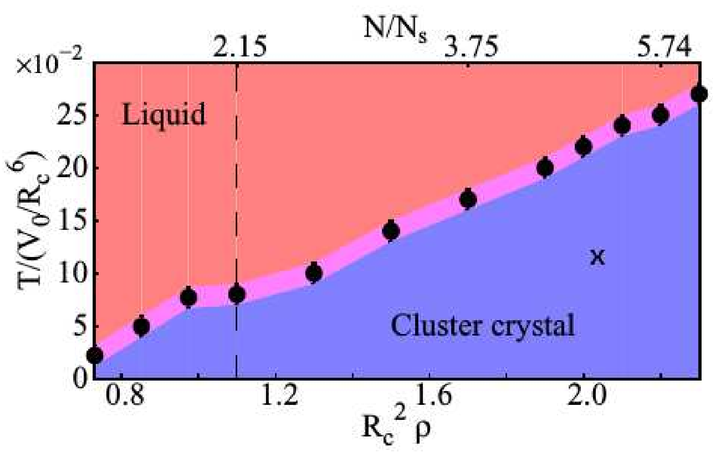
Soft-core potential representing e.g. the particle-particle interaction of branched colloids plus an hardcore term avoiding the colloids overlap [1].

$$\Phi_{sc}\left(r_{ij}\right) = \frac{A_0}{r_{ij}^6 + R_c^6} + \frac{B_0}{r_{ij}^6} \qquad (1)$$



The "free-model" phase diagram (no force, no ext potential)

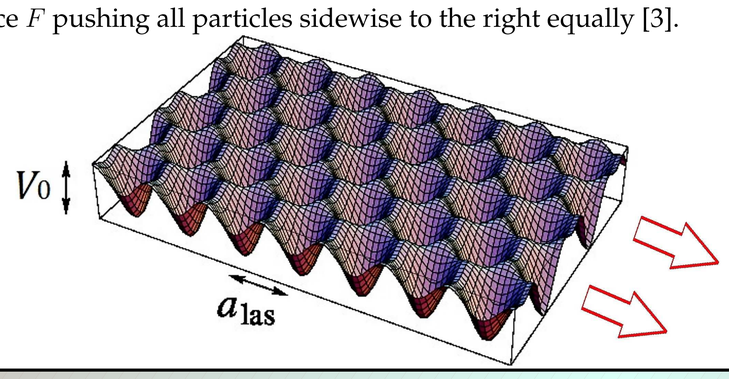
The "free" model has been studied in 2D [2]. The resulting phase diagram:



This phase diagram refers to the $B_0 = 0$ situation. In our study we adopt a very small value of B_0, so at $T \neq 0$ the phase diagram is not changed so much.

Our extra ingredients:

- a hexagonal local potential describing "corrugation" (experimentally it can be produced with a laser-light interference pattern).
  Corrugation amplitude: $\longrightarrow$ V_0; lattice spacing: a_{las}
- a lateral force F pushing all particles sidewise to the right equally [3].



Model details & units

All friction forces are to be compared with the static-friction force (depinning threshold) for a single collod at $T = 0$:

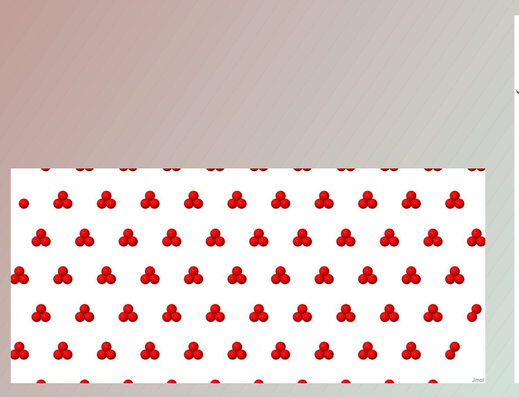
$$F_{1s} = \frac{8\pi V_0}{9 a_{las}}$$

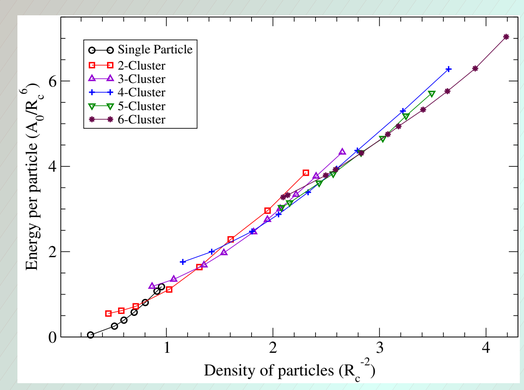
We set the Langevin damping to $\eta = 28$ in model units (strongly overdamped).

Physical quantity	system units
Length	R_c
Energy	A_0/R_c^6
Mass	m
Density	R_c^{-2}
Force	A_0/R_c^7
Time	$R_c^4\sqrt{m/A_0}$
Velocity	$R_c^{-3}\sqrt{A_0/m}$
Viscosity coefficient	$R_c^{-4}\sqrt{A_0\, m}$
Mobility	$R_c^4/\sqrt{A_0\, m}$

Zero-temperature phase diagram

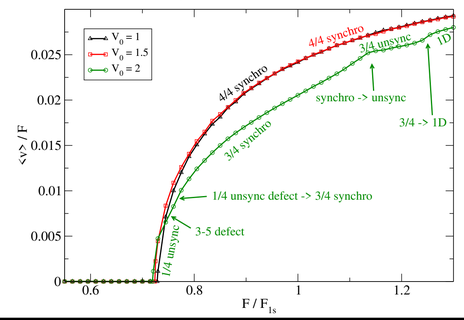
Example of the colloidal metasolids obtained by relaxing in absence of an external potential and force and comparison of the colloid-colloid interaction energy per particle, as a function of the number density of colloids for n-cluster configurations in the free model. The energetically favored densities for each of the n-cluster systems are taken as the starting points for all friction simulations.

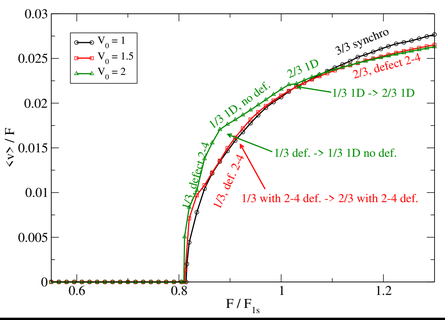




Results: Mobility of the n-cluster systems at $T = 0$

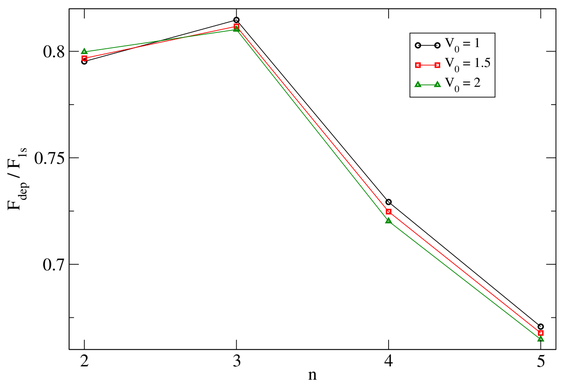
The plots show the mobility of the 3 and 4-cluster system, for $V_0 = 1, 1.5$ and 2.
The dynamics of the driven clusters is not trivial: we find that several phenomena can and do happen as the lateral force is increased. These phenomena do depend on the amplitude of the corrugation potential and on the number of colloid per cluster. We note the dynamical modes on the mobility graphs, where switching between modes can induce visible mobility anomalies. All these ordered dynamical modes are likely an artefact of $T = 0$, which tend to be washed out by thermal fluctuations in a more realistic finite-temperature regime.





Depinning force as a function of the number of colloids per cluster

The plot shows the depinning force, i.e. the static friction, F_{dep}/F_{1s}, for $V_0 = 1, 1.5$ and 2, as a function of the number of colloids per cluster. As shown, generally as the number of degrees of freedom grows the static friction decreases.



Discussion

We report an investigation of the frictional dynamics of a system of colloids in a meta-crystalline phase of clusters [4].

- With different densities of colloids, they naturally arrange themselves in clusters composed by different numbers of colloids.
- Systems of complex objects are characterized by a smaller depinning force.
- The mobility of the systems depends both by the number of colloids per cluster and by the amplitude of the external potential.
- The analysis of the dynamic of the systems revealed that the mobility is affected by several different phenomena.

  The present research sees two natural paths of expansion: the investigation of the thermal effects, and the investigation of the effects of lattice mismatch between the colloid-cluster spacing and the corrugated substrate periodicity. Thermal effects are important for making predictions of dynamical features which will be observed in real-life experiments. The lattice mismatch is likely to produce nontrivial solitonic sliding modes.

References

[1] L. Consonni, *Meccanismi di depinning in un modello di colloidi soffici*, thesis (University Milan, 2016), http://materia.fisica.unimi.it/manini/theses/consonni.pdf.

[2] R. Diaz-Mendez, F. Mezzacapo, F. Cinti, W. Lechner, and G. Pupillo, Phys. Rev. E **92**, 052307 (2015).

[3] A. Stenco, *Friction dynamics of a colloidal metasolid*, thesis (University Milan, 2016), http://materia.fisica.unimi.it/manini/theses/stenco.pdf.

[4] M. Rossini, *Cluster versus single-particle hopping in a colloidal model*, thesis (University Milan, 2017), http://materia.fisica.unimi.it/manini/theses/rossini.pdf.