Diffusion in colloidal monolayers: bridging the gap between two and three spatial dimensions

Alvaro Domínguez
Universidad de Sevilla
dominguez@us.es

It is well established that, unlike for a three-dimensional fluid, particle interactions prevent the hydrodynamic transport coefficients from being defined for a two-dimensional fluid due to the notorious "long-time tail" feature of the velocity autocorrelation.

A colloidal monolayer formed at a fluid interface builds a bridge between these two limiting cases, and it provides insight on the transition from three down to two spatial dimensions: the positions of the colloidal particles are constrained to a plane and the colloid thus resembles a two-dimensional fluid. But the exchange of particle momentum takes place in three-dimensional space because it is mediated by the ambient fluid in the form of hydrodynamic interactions.

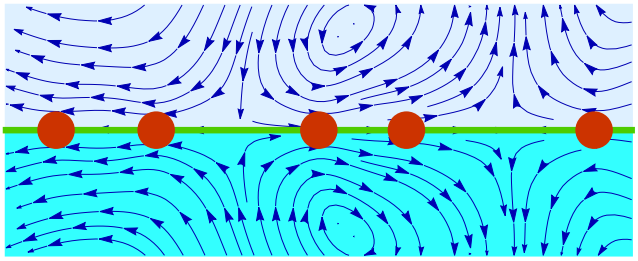

Fig. 1. Side view of a colloidal monolayer formed at the interface between two fluids, and sketch of the three-dimensional flows responsible for the hydrodynamic interactions.

Here we study the behavior of the colloidal diffusivity, which is the only hydrodynamic transport coefficient for the two-dimensional colloidal fluid. The starting point is the Smoluchowski equation, i.e., the Fokker-Planck equation for the colloidal particles in the overdamped regime with due account of the hydrodynamic interactions. We show that the diffusivity exhibits an intermediate behavior between purely two-dimensional and fully three-dimensional fluid: on the one hand, Fick's law, which pertains to *collective diffusion*, breaks down altogether [1, 2, 3], as confirmed experimentally [4]. On the other hand, the coefficient of *self-diffusion* (or single–particle diffusion) is finite [5], but the transitional nature of the monolayer shows up in a non-analytic dependence on the colloidal packing fraction [6], at odds with the case of a fully three-dimensional colloid.

[1] J. Bleibel, A. Domínguez, F. Günther, J. Harting, M. Oettel, *Soft Matter* **10**, 2945 (2014).

[2] S. Panzuela, R. P. Peláez, R. Delgado-Buscalioni, *Physical Review E* **95**, 012602 (2017).

[3] J. Bleibel, A. Domínguez, M. Oettel, *Physical Review E* **95**, 032604 (2017).

[4] B. Lin, B. Cui, X. Xu, R. Zangi, H. Diamant, S. A. Rice, *Physical Review E* **89**, 022303, (2014).

[5] R. P. Peláez, F. Balboa Usabiaga, S. Panzuela, Q. Xiao, R. Delgado-Buscalioni, A. Donev, *Journal of Statistical Mechanics: Theory and Experiment*, 063207 (2018).

[6] A. Domínguez, in preparation (2023).