

Diffusiophoretic instability in gravitationally stable colloidal systems

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We investigate non-equilibrium diffusiophoretic phenomena in colloidal suspensions subject to a stabilizing solute stratification, focusing on the onset of diffusiophoretic convective instability (DCI). While such systems are expected to remain gravitationally stable, we show that they can develop a transient convective instability under generic conditions. This behavior is highly unexpected, as it arises from diffusiophoresis—a mechanism that has never been observed to trigger convection in this class of gravitationally stable systems—which instead plays a dominant role in driving the system out of equilibrium.

We present experimental measurements of a colloidal suspension in a water–glycerol mixture brought into contact with a layer of pure water, generating a vertical solute concentration gradient (Figure 1a). Using shadowgraph imaging (setup Figure 1b), we characterize the temporal evolution of the system and identify two distinct regimes: a stable diffusive regime (Figure 1c) and an unstable regime exhibiting transient cellular convection (Figure 1d). The transition between these regimes is quantified through the time evolution of image variance and mapped in a phase diagram as a function of the initial solute and colloid concentrations, revealing the existence of a well-defined instability threshold.

To interpret these observations, we employ a minimal theoretical framework based on coupled transport equations for solute concentration and colloidal volume fraction, including diffusiophoretic coupling. A linear stability analysis of the evolving base state and one-dimensional numerical simulations without advective terms provide a first description of the mechanism leading to the instability. These results are complemented by preliminary two-dimensional simulations, used to validate the emergence and qualitative features of the observed convective patterns.

In addition, we report measurements performed in a Hele-Shaw cell, where the system is effectively confined in a thin geometry corresponding to a Darcy-like regime. These results demonstrate that diffusiophoretic effects can also drive instabilities in strongly confined systems, suggesting a broader relevance in porous media and thin-layer flows.

Our combined experimental and computational results provide a coherent picture of diffusiophoretic instabilities in multicomponent fluids and highlight the key physical mechanisms governing their onset. These findings point to a wider importance of diffusiophoresis in non-equilibrium systems, where it can act as a primary driver of macroscopic transport and pattern formation.

