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Settling behaviour of particles in Rayleigh-Benard convection

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Our numerical study evaluates the settling rate of solid particles, suspended in a highly vigorous, finite Prandtl number convection of a bottom heated fluid. We explore a broad range of model parameters, covering particle types appearing in various natural systems, and focus in particular on crystals nucleating during the cooling of a magma ocean. The motion of inertial particles within thermal convection is non-trivial, and under idealized conditions of spherical shaped particles with small Reynolds number it follows the Maxey-Riley equation (Maxey and Riley, 1983). Two scaling laws exist for the settling velocities in such system: for particles with small but finite response time, the Stokes' law is typically applied. For particles with a vanishing response time, a theoretical model was developed by Martin and Nokes (1989), who also validated their prediction with analogue experiments.

We develop a new theoretical model for the settling velocities. Our approach describes sedimentation of particles as a random process with two key constituents: i) transport from convection cells into slow regions of the flow, and ii) the probability of escaping slow regions if a particle enters them. By quantifying the rates of these two processes, we derive a new equation that bridges the gap between the above mentioned scaling laws. Moreover, we identify four distinct regimes of settling behaviour and analyze the lateral distribution of positions where particles reach the bottom boundary. Finally, we apply our results to the freezing of a magma ocean, making inferences about its equilibrium vs fractional crystallization. The numerical experiments are performed in 2D cartesian geometry using the freely available code CH4 (Calzavarini, 2019).

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