Hydrodynamic self-assembly in microrotor suspensions

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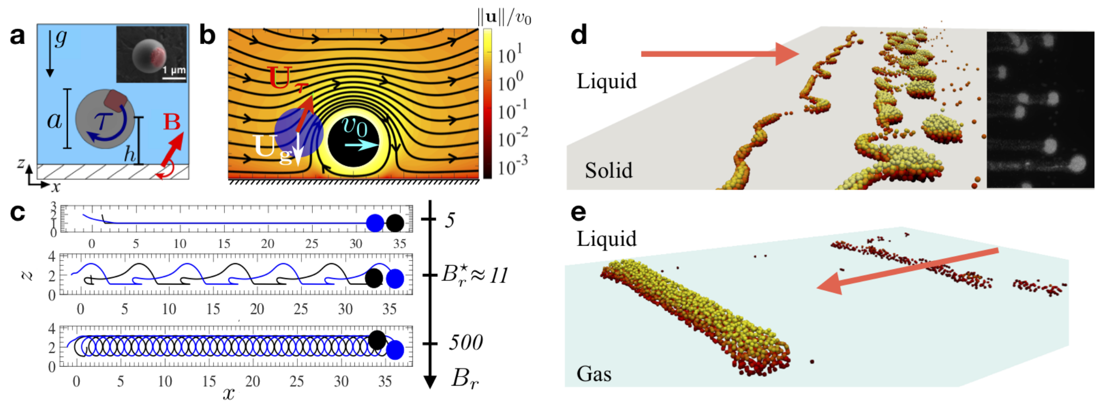

Figure 1. **a**, Sketch of a microrotor rotating above a solid/liquid interface ($\lambda = +\infty$). Inset : SEM image. **b**, Flow field around a microrotor (simulation). Colorbar : flow speed $\|\mathbf{u}\|$ normalized by the self-induced speed v_0. **c**, Trajectories of a pair of microrotors for $B_r = 5, 11$ and 500. **d**, Emergence of stable clusters from a fingering instability. Particle coloring : translational speed. Inset : top view of an experiment. **e** Collective motion above a gas/liquid interface ($\lambda = 0$) : motion reversal and no fingering instability.

Microrotors are small particles (diameter $a \sim 1\mu$m) rotated by a magnetic field, $\mathbf{B}$, parallel to an interface (Fig. 1a). Hydrodynamic coupling plays a crucial role in the dynamics of this system. The self-induced speed of an isolated particle, v_0, is much smaller than the velocity it induces on neighboring particles : $\|\mathbf{u}\|/v_0 \gg 1$ (Fig. 1b). This strong coupling leads to hydrodynamic bound states whose existence is conditioned by a dimensionless number : $B_r = U_\tau/U_g = \tau/mga$, where τ is the magnetic torque and m the particle mass. Above a critical value, $B_r^\star \approx 11$, the upward torque-induced flow, U_τ, can overcome downward gravity, U_g (Fig. 1b), and thus generate periodic orbits whose basin of attraction increases with B_r (Fig. 1c)[1]. When many particles are involved, these leapfrog orbits lead to the emergence of stable motile clusters made of hundreds of particles, translating at high speeds (Fig. 1d) [2]. The width of these structures is controlled by a fingering instability whose wavelength is set by the particle height. As the viscosity ratio between the outer fluid and the suspending liquid, $\lambda = \eta_{out}/\eta_{in}$, decreases from $+\infty$ (solid/liquid interface) to 0 (gas/liquid), the collective speed diminishes and changes sign below a threshold value $\lambda^\star > 0$, which depends on the particle arrangement and volume fraction. In parallel, the growth rate of the fingering instability vanishes for $\lambda = 0$, so that, when $\lambda = \lambda^\star$, the fingering instability develops without net translational motion. Our simulations and theoretical analysis show that the free-slip condition at the gas/liquid interface suppresses the transverse flows that drive the fingering instability, which allows for arbitrarily wide structures moving as a single, homogeneous, front (Fig. 1e).

Références

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