Electrophoretic bifurcation structure of a Janus nano-sphere under gravity

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A common geometry in electro-hydrodynamics exhibiting symmetry-breaking, is that of a spherical Janus particle (JP), which comprises of two hemispheres with two different properties (densities). Here, we investigate the influence of gravity on the dipolephoretic motion of a free metallo-dielectric JP suspended in a symmetric electrolyte and exposed to a spatially uniform ambient AC electric field, which can change its orientation from vertical (which aligns with the gravity field) to horizontal (perpendicular to the gravity field), as shown in Fig. 1 (left).

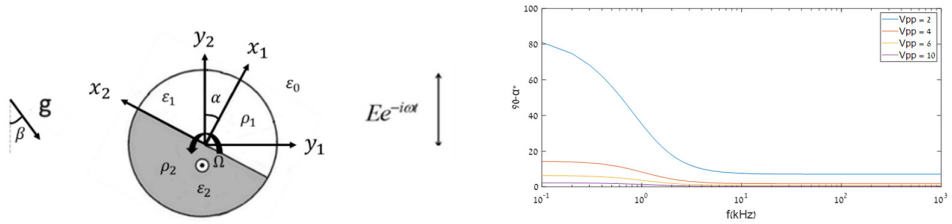

Figure 1. Definition sketch (left) and dependence of equilibrium position on frequency (right).

Under the assumptions of a 'weak field' and thin Debye layer, the electrostatic and hydrodynamic problems are linearized and solved for the unbounded case [1] (i.e., neglecting wall proximity). We formulate the planar equations of rigid-body JP motion [$y_1(t)$,$y_2(t)$,$\alpha(t)$] in a viscous Stokes regime (ignoring inertia).The resulting JP dynamics is investigated by employing a combination of analytical and numerical methods. The dynamical model is also validated by comparison with recent experimental results [2] (Fig.1 right), demonstrating similar qualitative behaviour where the resulting equilibrium angle decreases significantly with increasing frequency. Next, we investigate the influence of gravity on the JP bifurcation structure as a function of electric field orientation. The resulting analytically obtained bifurcation structure for the JP equilibrium [z=cos(α)], is verified numerically and reveals (Fig. 2) three distinct regions which incorporate coexisting stable (solid blue lines) and unstable (dashed red lines) angles.

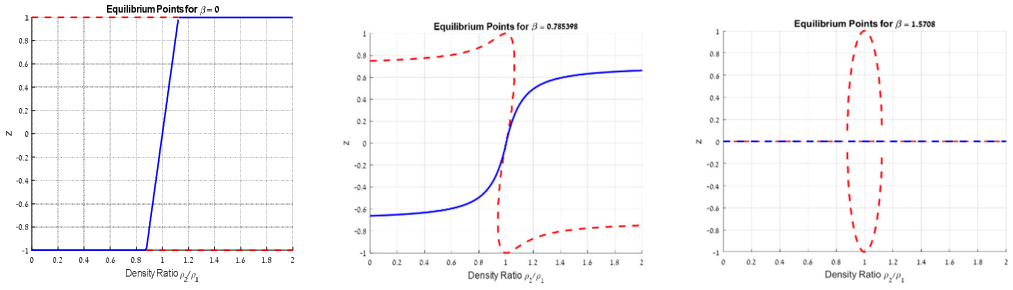

Figure 1. Bifurcation structure of equilibrium points as a function of JP density ratio for different orientations: β=0 (left), β=π/4 (center) and β=π/2 (right).

The implications of our findings are vast, with potential applications ranging from drug delivery systems to the design of probes based on Janus nanoparticles.

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[1] Miloh T, *Physics of Fluids*, **20**, **0**63303 (2008).
[2] Boymelgreen A. et al, preprint arXiv, **2312.03099** (2023).