Electronic Supplementary Material (ESI) for Lab on a Chip

Supplementary material

An isolated and perfectly spherical particle that is homogeneously polarized (dipole approximation) by an inhomogeneous AC-electric field $\vec{E}$ with spatially constant phase experiences the time averaged DEP force

$$\langle \vec{F}_{DEP} \rangle = 2\pi\varepsilon_0\varepsilon_\mathrm{m} a^3 \mathrm{Re}\left(\tilde{f}_\mathrm{CM}\right) \vec{\nabla} \cdot \vec{E}_\mathrm{rms}^2, \tag{1}$$

where ε_0 is the electric constant, ε_m is the relative permittivity of the liquid phase, a is the particle radius, $\mathrm{Re}\left(\tilde{f}_{CM}\right)$ is the real part of the Clausius Mossotti factor and $\vec{E}_\mathrm{rms}$ is the root mean square value of the electric field [54, 55].
The Clausius Mossotti factor

$$\tilde{f}_\mathrm{CM} = \frac{\tilde{\varepsilon}_\mathrm{p} - \tilde{\varepsilon}_\mathrm{m}}{\tilde{\varepsilon}_\mathrm{p} + 2\tilde{\varepsilon}_\mathrm{m}} \tag{2}$$

describing the frequency dependence of the induced particle dipole moment depends on the complex particle permittivity $\tilde{\varepsilon}_\mathrm{p} = \varepsilon_0\varepsilon_\mathrm{p} - j\frac{\sigma_\mathrm{p}}{2\pi f}$ and on the complex permittivity of the liquid phase $\tilde{\varepsilon}_\mathrm{m} = \varepsilon_0\varepsilon_\mathrm{m} - j\frac{\sigma_\mathrm{m}}{2\pi f}$, where ε_p, σ_p and σ_m are the permittivity of the particle material, the conductivity of the particle material and the conductivity of the liquid phase, respectively [54, 55]. Depending on the sign of the real part of the Clausius Mossotti factor, the time averaged DEP force acting on the particle can be directed towards regions of higher field intensities (positive DEP) or towards lower field intensities (negative DEP).

The drag force $\vec{F}_\mathrm{D}$ experienced by an isolated particle at low particle Reynolds number is governed by Stokes law
$\vec{F}_\mathrm{D} = 6\pi\mu a\left(\vec{U} - \vec{U}_0\right)$, where $\vec{U}$ is the particle velocity, $\vec{U}_0$ is the ambient flow field (which is approximately constant over the length scale of the particle) and μ is the dynamic viscosity of the fluid. For the typically low Stokes numbers and with no additional external forces acting on the particle, the DEP force and the drag force balance, which leads to the expression for the particle velocity

$$\vec{U} = \frac{\langle \vec{F}_\mathrm{DEP} \rangle}{6\pi\mu a} + \vec{U}_0 = \vec{U}_\mathrm{DEP} + \vec{U}_0. \tag{3}$$

As a result of the linearity of the Maxwell equations (for linear dielectrics) governing the electric field, $\vec{E}_\mathrm{rms} = \vec{g}(\varepsilon_\mathrm{m}, \mathcal{L})U_\mathrm{rms}$ is a linear function of the applied potential, where $\mathcal{L}$ is a set of parameters describing the electrode geometry. Hence, the DEP component of the particle velocity

$$\vec{U}_\mathrm{DEP} = 2\pi\varepsilon_0\varepsilon_\mathrm{m} a^3 \mathrm{Re}\left(\tilde{f}_\mathrm{CM}\right)\vec{g}(\varepsilon_\mathrm{m}, \mathcal{L})U_\mathrm{rms}^2 = \vec{K}\mathrm{Re}\left(\tilde{f}_\mathrm{CM}\right)U_\mathrm{rms}^2 \tag{4}$$

is a quadratic function of the applied potential U_rms with $\vec{K} = \vec{f}(\varepsilon_0\varepsilon_\mathrm{m}, a, \mathcal{L})$.