Effective Gaussian diffusion of optically trapped spheres along time-scales

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It is widely accepted that the random displacements of a Brownian particle follow a Gaussian distribution. The probability distribution $P(r,t)$ of the displacements of the particle is named as *propagator* or *van Hove autocorrelation function* [1]. Mathematically it is expressed through

$$P(r,t) = \frac{1}{[4\pi D_{\rm G}(\tau)\, t]^{d/2}} \, \exp\left(-\frac{\Delta r^2}{4 D_{\rm G}(\tau)\, t}\right), \quad (1)$$

where $\Delta r = r(t{+}\tau){-}r(t)$ is the displacement, τ is the lapse time between jumps, d is the system dimension. In Eq. (1), we define an *effective* Gaussian diffusion coefficient $D_{\rm G}(\tau)$, which depends on the time-lapse η of each displacement, but does not depend of the *absolute* time t. However, deviations from the Gaussian behavior should be expected to observed when the particle moves in complex fluids [2], or in a lower time-scale where the hydrodynamical effects are relevant [3, 4].

In this work, we study experimentally, through optical spectroscopy and optical trapping [5], the Brownian motion over six orders of magnitude in the time-scale, with a minimum time-step of 0.5 μs, of optically trapped melamine resin micro-sized spheres immersed in Newtonian and viscoelastic fluids. We obtain the Gaussian profiles of the displacements Δr for every fluid, taking into account that the effective diffusion coefficient depends of the time-lapse τ. The observations are in agreement with the Gaussian behaviour defined by Eq. (1), but $D_{\rm G}(\tau)$ behaves differently depending on the time scale. For Newtonian fluids, we observe that $D_{\rm G}(\tau) \simeq D_0$ in the diffusive regime, where D_0 is the usual Stokes-Einstein diffusion coefficient, $D_0 = k_{\rm B}T/6\pi\eta a$. Deviations from that constant value are observed at higher time-scales where the external optical forces are predominant, and also at lower time-scales, in the *trans-diffusive* or pre-ballistic regime. While the former behavior can be explained through the solution of the Fokker-Plank equation under a harmonic potential [6, 7], the latter is probably related to a more complex and generalized solution of the Fokker-Plank equation which includes ballistic and transdiffusive regimes [8].

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