

Memory effects in the orientational dynamics in nanoparticle suspensions

Miguel Ibáñez, Raúl A. Rica-Alarcón, María L. Jiménez

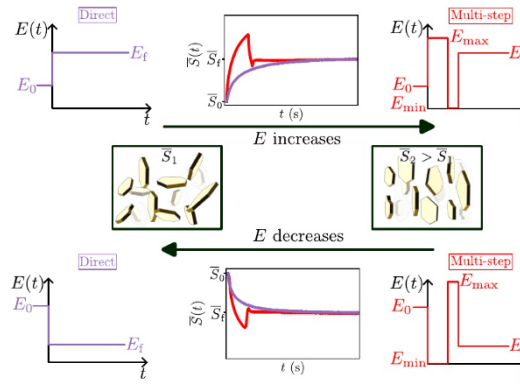
Universidad de Granada, Department of Applied Physics and Research Unit 'Modeling Nature' (MNat), Nanoparticle Trapping Laboratory, Granada, Spain

jimenez@ugr.es

The relaxation of stochastic systems after sudden perturbations is constrained by speed limits and often reveals memory effects that hinder attempts to accelerate their dynamics [1]. Here we demonstrate Kovacs-type [2] nonmonotonic relaxation in the electro-orientation of non-spherical nanoparticles and show how this memory effect limits simple acceleration protocols. Experimentally, the orientational dynamics is monitored optically through field-induced birefringence, which is proportional to the nematic order parameter [3]. When an AC electric field is first set to an extreme value until the birefringence reaches its target and is then switched to the target field (matched two-step protocol), the relaxation exhibits a characteristic Kovacs shoulder. We interpret this behavior within a theoretical framework based on the Smoluchowski equation for the orientational probability density. In the high-frequency AC regime, orientational relaxation is governed by induced dipoles, and the observed memory effect originates from polydispersity, which generates a spectrum of rotational diffusion coefficients and hence multiscale relaxation. Building on this insight, we design protocols that mitigate the detrimental effect of memory by sequentially suppressing the slowest active relaxation mode. Experiments on nanoparticle suspensions with different properties confirm these mechanisms, and we demonstrate substantial reductions in relaxation time compared with single quenches and matched two-step protocols with NaMt suspensions. More broadly, these results illustrate how memory effects emerge when many degrees of freedom are steered with a single control parameter and provide an experimentally accessible strategy for controlling multiscale stochastic dynamics [4].

Keywords:

Electric birefringence, Electro-orientation, Memory effects, Nonequilibrium dynamics, Stochastic dynamics



Schematic representation of the experimental system in a poorly aligned (left) and a strongly aligned (right) configuration. Upper and lower panels are the applied electric field protocols and the birefringence response.

References:

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