Reciprocal and non-reciprocal timescales in a viscoelastic fluid

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We experimentally investigate the transient recoil dynamics of a colloidal particle after it was dragged inside an optical trap, through a viscoelastic fluid. For long driving times, when the system has reached its steady state, we observe the onset of two timescales in the experimental recoil dynamics, which are in excellent agreement with the two eigenmodes of a linearly coupled two-bath particle model. Such linear behavior holds for a remarkably large range of driving velocities, where the measured timescales remain constant. Note that compared to a traditional Maxwell model, we thus report the appearance of a further relaxation time, which is not unexpected due to the finite friction of the colloid coupled to the viscoelastic bath.

Remarkably, our experiments are also in very good agreement with the model predictions outside of steady state regime, i.e., for partial loading and relaxation. Depending on the specific protocol, either the short or long timescale can be largely suppressed which may explain why single- and double-exponential recoils have been previously observed in different experiments.

Additionally, in this study we highlighted the distinction between reciprocal and non-reciprocal protocols, which lead to separate relaxation modes with two sets of timescales. As a result, a particle under free recoil (reciprocal) or trapped inside a strong trap (non-reciprocal) exhibits different relaxation time scales, as was confirmed in our experiments. Yet most experiments using optical tweezers usually lie between these two ideal protocols, in such a situation we thus expect to observe a more complex combination of relaxation modes. We expect our findings to be relevant under conditions where particles are exposed to non-steady shear forces as this is encountered e.g. in microfluidic sorting devices or the intermittent motion of motile bacteria within their natural viscoelastic surrounding.

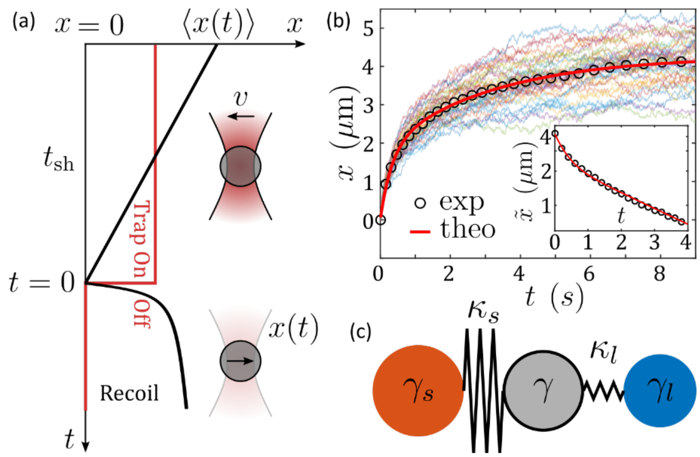

Fig. 1: (a) Sketch of a typical recoil protocol. The colloidal probe is first driven by an optical tweezers through the fluid at a constant velocity. At t=0s the optical trap is turned off and the probe is released. Because of accumulated strain in the fluid, the particle performs a recoil opposite to the direction of shear. (b) Typical recoil curves (colored lines) and the mean value <x(t> (black circles). The red solid line is a double-exponential fit. (c) Sketch of the two-bath particle model where the probe with friction coefficient γ is linearly coupled to two bath particles.

References:

[1] F. Ginot, J. Caspers, L. F. Reinalter, K. K. Kumar, M. Krüger and C. Bechinger, *New J. Phys.* **24**, 123013 (2022).