Ratchet effect in an aging glass

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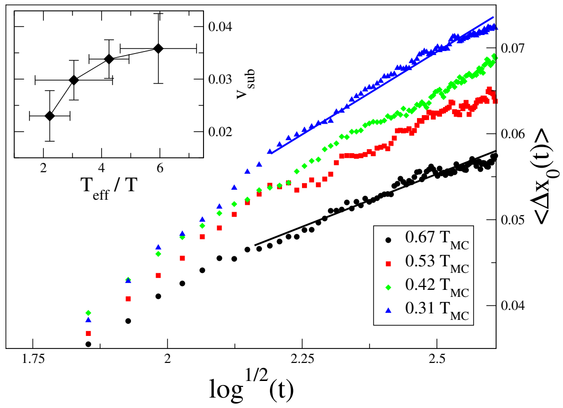

FIG. 1. (Color online) Main: Asymmetric intruder drift for different quench temperatures; linear fits yield sublinear velocities. Inset: v_{sub} versus T_{eff}/T.

In an irreversible environment, thermal fluctuations can be rectified in order to produce a directed current. After a few fundamental examples of historical and conceptual value, in the last twenty years a huge amount of devices and models —usually known as Brownian ratchets or motors— have been proposed. The necessary condition to obtain a ratchet is the simultaneous breaking of space and time-reversal symmetries. The time-reversal symmetry breaking is customarily obtained by coupling the system with reservoirs at two different temperatures: an asymmetric intruder in such a multi-temperature environment displays an average drift.

The present work, inspired from the latter scenarios with a continuous flow of energy in a non-thermalized medium, shows a study of the ratchet phenomenon in the aging dynamics of fragile glass-formers. In such a system the ratchet is formed by the asymmetric interaction of a single particle, the intruder, with all the other particles of the system. The two temperatures necessary to have an out-of-equilibrium environment are represented by the quench temperature T and the effective temperature T_{eff} of the still non-equilibrated modes of the aging glass former. In order to observe a directed motion we quenched the system well below its mode coupling temperature, T_{MC}, where the equilibration time exceeds the simulation time and an effective temperature T_{eff} can be defined and measured from the violation of the equilibrium fluctuation-dissipation relation. In this situation a net average drift is observed, see fig. 1, steady on a logarithmic time-scale:

$$\langle \delta x(t) \rangle \sim \log^{1/2}(t) \qquad (1)$$

The *subvelocity* of the intruder, defined as $d\langle \delta x(t) \rangle / d\tau$ with $\tau = \log^{1/2}(t)$, grows when the ratio T_{eff}/T is increased, namely when the quench temperature is lowered: this corresponds to the general behavior of thermal ratchets in contact with two thermal reservoir. The results of a similar experiment are presented also for an *asymmetric* version of the Sinai model, which describes the diffusion of an intruder through a random correlated potential. Its long-time dynamics is ruled by activated events and is characterized by a logarithmic time-scale: for this reasons it appears to be a well fitted candidate to reproduce the previous experiment in a more controlled setup. The numerical study of the *asymmetric* Sinai model shows a behavior in striking similarity with those of Fig. 1 for the glass-former model: a drift, still growing on a logarithmic time-scale, is observed only when both time reversal and spatial symmetry are broken. The comparison between the two models studied suggests that the non-equilibrium drift is mainly ruled by activated events and that the observed phenomenon is quite general and does not depend on the specific model.

In conclusion, through numerical simulations in different models and different choices of the quench temperature, always chosen in the deep slowly relaxing regime, we have given evidences of the existence of a "glassy ratchet" phenomenon. The drift velocity slowly decays in time and can be appreciably different from zero for at least three orders of magnitude in time. The overall intensity of the drift, measured in terms of a "sub-velocity", is monotonically increasing with the distance from equilibrium, i.e. with the ratio T_{eff}/T. This observation supports the idea of regarding the ratchet drift as a "non-equilibrium thermometer": it can be used as a device capable to say how far is a system from equilibrium. Recent theoretical and experimental advances in the study of functionalized or "patchy" particles [2] promise an experimental verification of our hypothesis in the near future.

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