# Entropy consumption and production in a slowly sheared jam

**Nonequilibrium Fluctuation Relation for Sheared Micellar Gel in a Jammed State**

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A growing family of Fluctuation Relations or Theorems establish the connection between the macroscopic Second Law of thermodynamics and the statistical mechanics which forms its microscopic basis. These relations make quantitative statements about the probability of rare entropy-consuming events relative to the normal entropy-producing events that dominate the behaviour of macroscopic systems. In all situations for which theoretical *derivations* of such theorems exist, such as refs. [1-4] of the paper by Majumdar and Sood under discussion, the fluctuations arise from a *thermal* bath characterised by a temperature, and the driving is superposed on these fluctuations. There are however many systems in which fluctuating steady states exist only *because* of continual external forcing, and not molecular chaos. The simplest example is a sheared powder, in which fluctuations arise from the chaotic nature of interparticle collisions, while dissipation is predominantly into the macroscopic number of internal degrees of freedom of each grain. It is clear however that any system with a large and well-defined separation of scales, in which the dynamical variables of interest can feed their energy into a macroscopic number of microscopic coordinates, lies in this class. Sayantan Majumdar and A.K. Sood study the creep behaviour of one such system, polymeric micelles in a jammed state whose microstructure is probably a random packing of columnar hexagonal domains. They show that for small stresses, below the value at which the system flows freely, the shear-rate at constant stress fluctuates substantially. Irregular, hesitant flow in a disordered, jammed system is no surprise. However, an analysis of the fluctuations reveals that the system doesn't just alternate between stuck and moving, but occasionally flows against the direction in which it is being pushed, feeding energy to the shearing machinery. Majumdar and Sood analyse the statistics of these rare, entropy-consuming events.

They study the ratio of probabilities (in my notation) $P_\tau(\dot\gamma)/P_\tau(-\dot\gamma)$ of observing a forward shear-rate $\dot\gamma$ relative to a retrograde shear-rate $-\dot\gamma$, in a description averaged over an observation time $\tau$, and find it varies exponentially with $\dot\gamma\tau$, *even when $P$ is substantially non-Gaussian.* Rescaling appropriately by the applied stress and the sample volume, and drawing an analogy to the known fluctuation relations, they extract an effective temperature $T_{eff}$ whose dependence on stress and sample size they study.

Why is this study important? First, it shows that fluctuation relations are much more widespread than their initial derivations would have suggested. Second, it tells us that driven systems which produce their own noise as a result of the driving behave in a manner surprisingly similar to those in which fluctuations arising from thermal noise are modified by driving forces like shear. Third, it forces us to ask whether the effective temperature emerging from the analysis has any significance in a new thermodynamics of driven matter.