Rheology and Tribology at the Nanoscale: From Molecular Junctions to Macroscale Suspensions

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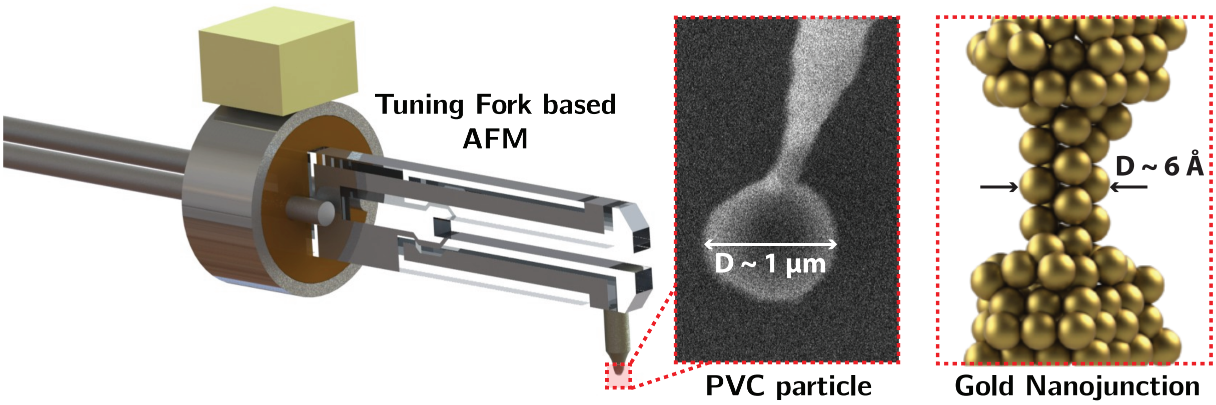

In this seminar, we will present two problems involving the study of dissipative processes at the nanoscale, using a quartz-tuning fork based Atomic Force Microscope.

First, we will focus on the internal dissipation at play during the plastic deformation of nanosized metallic gold junction**.** Despite extensive documentation of plastic deformation processes in micro-sized samples, there is up to now no clear understanding of the mechanisms governing plastic flow in nanoscale systems. Here, we combine electrical and rheological measurements on nanoscale gold junctions of only few atoms width, and study the onset of plastic flow in those molecular systems. By submitting the junction to increasing sub-nanometric deformations, we uncover a transition from a purely elastic regime to plastic-like flow in the junction, up to the complete shear melting of the junction. This typology is reminiscent of the behavior of macroscopic complex fluids **[1]**, here uncovered for a "molecular foam". We rationalize our results in the framework of a harmonically driven Frenkel-Kontorova model. Our measurements allow us to measure the critical yield force governing the onset of plastic flow in the junction, as a function of size. In those molecular systems, plasticity seems to be limited by the direct sliding of atomic planes under shear, as predicted for dislocation-free systems.

Second, we will focus on the tribological response of two sliding micron-sized particles in solvent, and put our results in the context of the rheology of macroscale non-brownian suspensions. Flowing suspensions of particles typically show a range of non-newtonian behaviors, such as shear thinning and shear thickening. Although well-characterized on the macroscale, the microscopic mechanisms responsible for those behaviors are still poorly understood. Here, we measure the pairwise frictional profile between approaching pairs of PVC and cornstarch particles in solvent. We report a clear transition from a low-friction regime, where pairs of particles support a finite normal load, while interacting purely hydrodynamically, to a high-friction regime characterized by hard repulsive contact between the particles and sliding friction. Critically, we show that the normal pressure needed to enter the frictional regime at nanoscale matches the critical stress at which shear thickening occurs for macroscopic suspensions **[2]**. Further measurements allow us to rationalize the shear thinning regimes observed before and after the shear thickening transition **[3]**. Our experiments bridge nano and macroscales and provide long needed demonstration of the role of local inter-particle frictional interactions in the rheology of suspensions.

[1] Yielding and flow of monodisperse emulsions. T.G. Mason, J. Bibette, D.A. Weitz. **Journal of Colloid and Interface Science**, 179(2), 439-448, (1996).
[2] Pairwise frictional profile between particles determines discontinuous shear thickening transition in non-colloidal suspensions. J Comtet, G Chatté, A Niguès, L Bocquet, A Siria, A Colin. **Nature Communications** 8 (2017).
[3] Shear thinning in non-Brownian suspensions. G Chatté, J Comtet, A Niguès, L Bocquet, A Siria, G Ducouret, F Lequeux, N Lenoir, G Ovarlez, A Colin. **Soft Matter** (2018).