Temperature control of the solid-liquid interfacial rheology

M2 Internship

Laboratory names: LPENS (PSL – ENS) and LPS (Université Paris-Saclay)
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Thesis possibility after internship: YES
Funding: POSSIBLY (ANR in course of evaluation)

Scientific context

Liquid slippage on low friction solid surfaces can dramatically enhance the permeability of nanoscale channels[1]. The study of liquid-solid friction has established as a central topic in **nanofluidics**. The friction stress σ at a solid-liquid interface can be related to an interfacial friction coefficient λ through $\sigma = \lambda V_s$, where V_s denotes the slip velocity. Traditionally, slip at the solid-liquid boundary can be characterized using the **slip length**, b, defined as the distance over which the liquid velocity profile would extrapolate linearly to reach the wall velocity. The slip length arises as the ratio between the liquid viscosity in bulk, η, and the interfacial friction coefficient: $b = \eta/\lambda$. Both η and λ are temperature-dependent, which implies that the slip length, b, is also a function of temperature. In a simple Arrhenian model of friction, both η and λ decrease with rising temperature, which imply that the combined effect of temperature on the slip length is not straightforward[2]. Going further, members of our consortium have recently put forward situations in which even the Arrhenius picture can fail[3–6]. Temperature therefore opens an unprecedented and efficient window on the intimate molecular dynamics of fluids at surfaces. On the experimental side, this has been barely investigated and existing research literature reports varied observations regarding how *b* changes with temperature. **The aim of this research project is therefore to get a unified understanding of the effect of the temperature on friction, since temperature is a unique tool to change this transport coefficient**. **The second aim is to seek for systems where temperature has a drastic impact on friction and slip, making temperature a powerful tool to control friction in nanofluidic systems.**

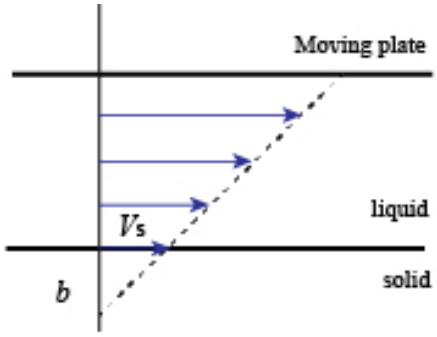

Figure 1: Definition of the slip length.

Internship program

MD numerical simulations on Lennard-Jones fluids have shown that **interfacial friction can drastically decrease when lowering the temperature.** This was confirmed by experiments performed on polymer melts far above their glass temperature**.** On the other hand, recent experiments have shown for glycerol, a common glass forming liquid, experiments performed by the ENS team with a tuning-fork based Surface force apparatus (TF-SFA) a **2-orders of magnitudes increase of slippage with decreasing temperature by only 30 °C, associated with a drastically non-Arrhenian friction coefficient**. Différent explanation could lead to such a discrepancy between these two models. A first approach could be that interfacial friction should be based on the **coupling of collective excitations in the fluid and in the solid surface** (electron, plasmons, phonons, …) for the glycerol/mica surface. **Such couplings are strongly temperature dependent**, with dependence at odds with Arrhenius processes (e.g., due to thermal filling of the modes).

We will use a new setup to probe the liquid-solid interface with an automatic control, an environmental chamber controlling humidity and temperature. The idea is to integrate to the now classical tuning-fork SFA a Michelson interferometer to measure the glass sphere's position, delivering both an AC-dynamic signal and a static deflection signal getting a profound integration capabilities and the adaptability to interchange surfaces while maintaining the same glass sphere.

During this internship/thesis we will obtain a comprehensive evaluation of solid-liquid friction across distinct liquid categories. Specifically, we will focus will on glass-forming liquids, exemplified by substances such as **glycerol and glycerol-water solutions**. We will use a new We will modify **two key parameters: temperature and the surface energy of the walls**. The surface energy will be varied using well controlled silanization, a technique regularly used in the MMOI group and which necessitates a really good control of the environment. By systematically varying these conditions, we aim to unravel the nuanced interplay between liquid types and frictional behavior, potentially offering fresh insights into the intricacies of solid-liquid interactions.

Collaboration: The internsip will be co-supervised by Frédéric Restagno (MMOI team) and Lydéric Bocquet (Micromegas team).

Job requirements: The candidates should have a strong background in physics and should be interested in soft matter, statistical physics and hydrodynamics. The work will be largely experimental. Depending on the interest of the candidates, some collaborations with a group of MD numerical simulations (in Lyon) will be possible during the PhD.

References

1. Bocquet, L. & Charlaix, E. Nanofluidics, from bulk to interfaces. *Chem. Soc. Rev.* **39**, 1073 (2010).
2. Herrero, C., Tocci, G., Merabia, S. & Joly, L. Fast increase of nanofluidic slip in supercooled water: the key role of dynamics. *Nanoscale* **12**, 20396–20403 (2020).
3. Kavokine, N., Bocquet, M.-L. & Bocquet, L. Fluctuation-induced quantum friction in nanoscale water flows. *Nature* **602**, 84–90 (2022).
4. Coquinot, B., Bocquet, L. & Kavokine, N. Quantum Feedback at the Solid-Liquid Interface: Flow-Induced Electronic Current and Its Negative Contribution to Friction. *Phys. Rev. X* **13**, (2023).
5. Lafon, S., Chennevière, A., Restagno, F., Merabia, S. & Joly, L. Giant slip length at a supercooled liquid-solid interface. *Phys. Rev. E* **107**, (2023).
6. Lizée, M., Mariette, G., Bocquet, L. & Siria, A. Drastic reduction of dynamic liquid-solid friction in supercooled glycerol. Preprint at http://arxiv.org/abs/2309.15957 (2023).