Preface to the special section on nano- and mesoscale friction

Eran Bouchbinder, Department of Chemical Physics,
Weizmann Institute of Science, Israel

Adam S. Foster, Department of Applied Physics, Aalto University, Finland

Oğuzhan Gürlü, Department of Physics Engineering, Istanbul Technical University,
İstanbul, Turkey

Ernst Meyer, Department of Physics, University of Basel, Switzerland

Susan Perkin, Department of Chemistry, University of Oxford, UK

Andre Schirmeisen, Institute of Applied Physics,
Justus-Liebig-University Giessen, Germany

Astrid S. de Wijn, Department of Physics, Stockholm University, Sweden

Recent widespread efforts to characterize the mechanisms of friction in micrometric structures (mesoscale) down to the size range of atoms and molecules (nanoscale) allow us to come closer to the ultimate goal of improving our control of friction, adhesion and wear by design. The potential impact of this interdisciplinary research, known as nanotribology, on technology and everyday life is widespread, with key applications in industrial safety, energy and materials efficiency, and more generally sustainable development and economics. Europe has a very strong research community in nanoscale friction, which encompasses physics, materials science, chemistry, earth and life sciences, with excellent links between academic and industrial actors. The network of researchers has been expanding rapidly in the past few years, and this special section highlights some of the work developed in this community.

Bridging tribological mechanisms at different scales

Frictional phenomena are known to span and couple a wide range of length and time scales, and to exhibit various collective effects. Consequently, understanding friction entails a multi-scale effort. In this special section, the collective dynamics of an ensemble of macro- scopic grains under shear are investigated [134001]. Possible relations to lubrication of systems at smaller scales are raised. In another work [134007], solid lubrication by graphene flakes is shown to be more effective compared to lubrication by a full graphene layer as a result of a collective mechanism that emerges from the independent behaviour of the flakes.

Tuning nanofriction

Approaches to the tuning of friction on all length scales often employ lubricants and surface treatments. With current experimental techniques and numerical simulations, it has become possible to probe the nano-scale mechanisms by which these methods change the friction. In this special section, several works investigate the effects of different structure and thickness of the tribolayer [134001, 134007, 134005, 134004]. In [105396], for example, Krass et al investigate how the friction depends on the number of layers of lubricant molecules in the boundary lubrication regime.

Others investigate the mechanisms by which surface treatments such as patterning [134008], and coatings with specific properties [134009, 134003] can be used to change friction. There is currently also an increasing interest in changing friction using external fields. Paronuzzi Ticco et al [134006] investigate the effect of an oscillating external field on the sliding of colloidal monolayers, with highly nontrivial results.

Confined systems under shear

Friction and lubrication between two solids is most often mediated by a thin film containing simple or complex fluid or a confined solid lubricant. The study of these 'confined systems' under shearing conditions has been a focus of work in the nanotribology community; the molecular-level details of fluid film shear are gradually being revealed. Included in this special section are papers contributing to this direction of work, ranging from the molecular to the macroscopic scale. The contribution by Krass et al [134004] describes some of the most delicate and revealing AFM nanotribology measurements yet published, detecting the shear response of hexadecane on graphite and revealing stepwise increases in viscous and elastic response as the number of layers of alkane is sequentially reduced. Working at a very different length scale, Galmiche et al [134005] present a new method for imaging the velocity profile of lubricant films in an elastohydrodynamic contact; a base fluid doped with a Europium dye is demonstrated to deviate from Couette flow as the pressure across the lubricant is increased.

Controlled nano movements

Within the European Cooperation in Science and Technology (COST) action MP1303 the research direction controlled nano movements describes the predictive understanding and control of the fundamental processes underlying nanofriction and adhesion by exploiting nano-object manipulations. This strategy serves as a complementary method to study interfacial friction as a function of parameters difficult to access and modify in a standard friction force microscope. In particular, nanoparticles allow a broader choice of structurally well-defined material pairings at the interface and/or permit the varying of the contact size over a wide range. Nano-objects of recurring interest are graphene flakes sliding on graphite; indeed this was one of the first material systems where superlubricity was shown to exist. In [134007] the authors found, in simulations, superior sliding friction properties of graphene flakes stuck between two graphene layers as opposed to a full graphene layer in between them. The reason for this phenomenon is found to be related to the non-simultaneous collective translations of the flakes. In a different vein, in [134006] Paronuzzi Ticco et al perform a theoretical analysis of Shapiro steps during the sliding of a monolayer under DC and AC force modulation. While this work was explicitly directed to the sliding of optical lattice trapped colloidal particle monolayers, this may also be relevant to nanoparticle manipulation under external force control.

Industrial applications

For real life applications, friction is always at both ends of the spectrum: either it is unwanted or it is needed to be very high. For instance, the least amount of friction is required in the moving parts of a bike, yet the highest possible friction is required while making a knot in one's shoelaces before riding the same bike. The problems with friction in any industrial application do not need to be mentioned in detail. From the increase in the energy expenses, to the replacement costs of the worn-off equipment parts, friction is the central problem. Although in larger scale applications most of the problems due to unwanted friction can be solved routinely, problems due to friction at much smaller scales, such as in MEMS applications, cannot be dealt with using the conventional brute force solutions of the heavy industry. This clear and present problem with friction is due to the inexistence of a complete understanding of the concept itself. Without a proper understanding, tuning friction in any application is next to impossible. Within COST action MP1303, the tasks undertaken include the reflection of the results of fundamental research to applied problems. One way of building such an information bridge is looking at the friction problem at the atomic scale and then building up from there on. Investigation with proper imaging tools is a good way to start. The study of friction at the sub-nanometer scale with the help of atomic force microscopy gives invaluable information in the quest for solving the puzzle of the nature of friction [134006]. The study of friction in action with further advanced imaging methodologies helps along with these efforts [134005]. Although they are agents that help in the reduction of friction between moving parts, possible changes in the characteristics of such chemicals in action [134001] and under confinement [134004] needs to be understood. Ultimately, rather than using intermediate materials for the reduction or the control of friction, modification of the surfaces in contact, such as patterning them at the nano scale, may be a pathway to tune friction [134008]. The papers in this issue reflect the multidisciplinary and multidimensional nature of this COST network.

References

All citations refer to the special section on nano- and mesoscale friction in J. Phys.: Condens. Matter **28** (2016).