PHYSICS

# Controlling friction atom by atom

## A cold-atom system is used to probe atomic friction on the scale of single atoms

*By* **Ernst Meyer**

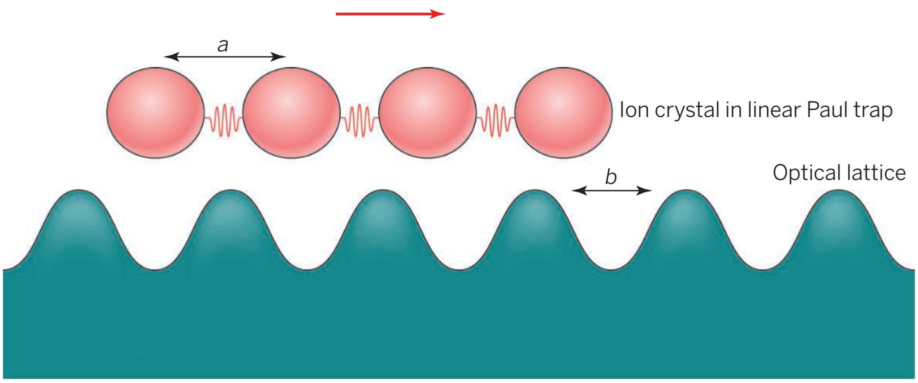
Friction is a phenomenon of great technological relevance. The empirical laws of friction date back to the investigations of Leonardo da Vinci (1452 to 1519) and Guillaume Amontons (1663 to 1705). Thus, we have known for a long time that friction is proportional to the force normal to a surface and independent of the geometrical contact area. We also know that friction is one of major sources of energy loss, whereby a large amount of energy is dissipated into heat. In some cases, suitable surface preparation can lead to superlubricity, which corresponds to a state with extremely low frictional forces, where energy dissipation is at a minimum (*1*). On page 1115 of this issue, Bylinskii *et al.* (*2*) describe a cold-atom system that takes us to the ultimate limit of friction. They show that a defined number of ions, from one to six, can be moved across an optical lattice to study the elementary processes of atomic friction.

The mechanism behind superlubricity has remained unknown so far. It is possible that the surface chemistry—for example, coverage with thin molecular layers or structural properties of the interface—might play an important role. Although the Frenkel-Kontorova (FK model) (*3*, *4*) predicts that two incommensurate crystals (*5*) might lead to superlubric conditions, little is known about the influence of the atomic structure of the sliding interfaces under real experimental conditions. This subject has become the focus of fundamental research, where a number of modern experimental setups, such as quartz microbalance, surface force apparatus, or atomic force microscopy, were applied and advanced models were developed to unveil the secrets of the fundamental processes of friction (*6*).

The technique presented by Bylinskii *et al.* uses a small number of ions trapped to form an ion crystal in a linear Paul trap (see the figure). This ionic crystal is then positioned close to a periodic optical lattice, and can be pulled across the periodic lattice, analogous to pulling a sledge across the ground. In contrast to the macroscopic sledge, however, the authors have full control over the number of ions in the trap, which they varied between one and six. A stick-slip motion was observed for the commensurate cases, where the ions stick in the valleys of the periodic lattice until the applied force is large enough for the ions to slide together to the next valley. When the degree of commensurability was reduced, a transition to smooth sliding, or superlubricity, was seen. In this case, the ions move asynchronously, and the overall frictional force is drastically reduced. From the FK model, the transition from stick-slip to smooth sliding is expected for the incommensurate case. However, the FK model was developed for a crystal of infinite size, and it was expected that small crystals might show a different behavior. Therefore, it is surprising that such a drastic reduction of friction in the incommensurate case compared to the commensurate case (by a factor of 10 for two ions to 100 for six ions) is observable with only a few atoms.

The present experimental setup is a versatile atomic friction simulator, which allows the experimentalist to control the number of atoms, the interaction strength, and the degree of commensurability between ion lattice and optical lattice. Although the temperature of the ions was only in the sub-millikelvin regime, it was observed that thermal excitation plays an appreciable role. Comparison with simulations showed that a model without thermal excitation would lead to discrepancies, which validates the thermal lubricity model introduced by Krylov and Frenken (*7*).

The experiments by Bylinskii *et al.* have shown that atomic friction can be controlled by the use of ion traps. The relevant parameters, such as the number of atoms in contact and the periodicities of the slider and the surface, are determined, and subsequently the effects of commensurability can be controlled with high accuracy. The limits of the experiments are the pure one-dimensional character and the quite artificial way to create physical interactions with optical lattices, which is rather far removed from the world of material science. However, the experiments have shown that the concept of commensurability can be realized with only a few atoms. Future experiments may further elucidate the fundamental processes of friction. Possibly, novel regimes may be explored, where quantum-mechanical tunneling becomes important, and the fascinating world of quantum mechanics comes into reach. ■




**The atomic friction simulator.** An ion crystal confined in a linear Paul trap is moved across a periodic optical lattice. Friction is found to depend strongly on the commensurability of these two lattices, even for systems with only two to six ions included in the trap.

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ILLUSTRATION: ADAPTED BY P. HUEY/SCIENCE

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