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Scientists from the Institute of Physics of the ASCR have a part in an important discovery: Friction on the microscopic level depends on the orientation of the surface.

Friction is defined as the resistance acting between two macroscopic objects, which are in mutual contact and moving in relation to one another. We encounter friction in our everyday activities and annually cause significant financial damages as a result of energy losses or the wear and tear of materials. Its deeper understanding is therefore one of the main priorities, which contribute to the lower energy demands of our society. The essence of friction was dealt with already by Leonardo da Vinci. In the 18th century, C. A. de Coulomb formulated a simple law, which says that friction is a directly proportionate product of the force pressing the two objects together and the coefficient of friction, where the coefficient of friction is an empirical material property. However, it is still true after more than three centuries of intensive research that we are still far from a complete understanding of the physical processes connected with the mechanism of friction.

The last research results show that friction on the microscopic level is strongly influenced by the atomic structure touching the surface. In other words, friction between two objects can be understood as the making, stretching and subsequent breaking of thousands of atomic asperities. One of the fundamental keys for understanding the mechanism of friction on the atomic level is therefore the opportunity to measure the lateral forces (i.e. the forces parallel with the surface) acting between the individual atoms on the surfaces in contact, which is not a trivial task.

In a work published in the journal Physical Review Letters (see link here), we have in cooperation with colleagues from the university in Regensburg presented a new concept of a direct measurement of the lateral forces (of friction) on the atomic level using a modified atomic force microscope. This advance opens entirely new possibilities in the study of friction. The importance of the work is proved by the fact that the article was selected by the editors of the journal for inclusion in the section Editors' Suggestion and Physics Viewpoint (see here). The article was also referred to in the pages of the journal Physics Today (see here).

The new arrangement of the microscope allows the precise setting of the lateral forces between two objects. As proof, we have conducted measurements of the lateral forces with atomic resolution on the chemically passive surface of silicon. These measurements have clearly shown the directional dependence of the lateral forces. In other words, the friction between two macroscopic objects is dependent on the mutual orientation of the atomic structure of the surfaces of the objects touching. Moreover, the theoretical calculations performed simulating the interactions of the apex of the microscope with the given surface of the silicon provide outstanding agreement with the measured experimental data. This agreement allows us a deeper understanding of the origin of the directional dependence of the lateral forces, i.e. friction, on the atomic level – as a consequence of the different excitations of the vibrational degrees of freedom, so-called rocking modes, which is represented by the movement of two surface atoms of silicon oscillating perpendicular to the surface in the opposite phase (for a graphic interpretation, see the link). These results show that the atomic structure of the surface and its vibration spectrum play an important role in the directional dependence of friction.

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Pictorial supplement:
Fig. 1: A schematic model of the surface of silicon (100), which is created by the characteristic pairs of Si atoms (so-called dimers), in two various orientations to the oscillating apex of the microscope, which in this configuration allows the direct detection of lateral forces with atomic resolution.