Atomic scale friction phenomena

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Friction has long been the subject of research: the empirical da Vinci-Amontons friction laws have been common knowledge for centuries. Macroscopic experiments performed by the school of Bowden and Tabor revealed that macroscopic friction can be related to the collective action of small asperities. Over the last 25 years, experiments performed with the atomic force microscope have provided new insights into the physics of single asperities sliding over surfaces. This development, together with the results from complementary experiments using surface force apparatus and the quartz microbalance, have led to the new field of nanotribology. At the same time, increasing computing power has permitted the simulation of processes that occur during sliding contact involving several hundreds of atoms. It has become clear that atomic processes cannot be neglected when interpreting nanotribology experiments. Even on well-defined surfaces, experiments have revealed that atomic structure is directly linked to friction force. This chapter will describe friction force microscopy experiments that reveal, more or less directly, atomic processes during sliding contact. We will begin by introducing friction force microscopy, including the calibration of cantilever force sensors and special aspects of the ultrahigh vacuum environment. The empirical Prandtl-Tomlinson model often used to describe atomic stick-slip results is therefore presented in detail. We review experimental results regarding atomic friction, including thermal activation, velocity dependence and temperature dependence. The geometry of the contact is crucial to the interpretation of experimental results, such as the calculation of the lateral contact stiffness. The onset of wear on the atomic scale has recently been studied experimentally and it is described here. The chapter ends with a discussion of recent experiments aimed to detect the dissipative forces acting when a sharp tip is moved parallel and very close to a solid surface without being in contact with it, or when small entities such as single polymer chains, graphene nanoribbons or large organic molecules are manipulated.

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