# Of Friction and the Da Vinci Code

MSD investigators Miquel Salmeron and Frank Ogletree, working in collaboration with scientists from Ames Laboratory, have used principles developed originally by Leonardo Da Vinci and unique materials called "quasicrystals" to perform the first study of the effects of periodicity in a crystalline lattice on frictional forces affecting that material. Using an instrument that combines the functionality of Atomic Force Microscopy (AFM) and Scanning Tunneling Microscope (STM), researchers found that friction along directions in which the atomic arrangement is periodic is much greater than along directions with aperiodic ordering.

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At the atomic level, when two surfaces come in contact the chemical bonds and clouds of electrons in their respective atoms interact and create frictional forces that cause energy to be dissipated. Da Vinci was the first to hypothesize that surfaces with commensurate (matching) structures would interlock intimately and lead to high lateral friction. This analysis is valid even on the atomic scale; surfaces of identical crystallographic orientation have higher friction than surfaces of differing orientation. Commensurability, however, is only one aspect of the friction problem and is difficult to evaluate experimentally because the contacting materials are usually different and therefore almost always incommensurate.

To isolate frictional effects due to periodicity alone, and not to other factors such as chemical differences between surfaces, the LBNL team studied decagonal quasicrystals (pentagonal rotation symmetry but no periodic translation symmetry) of an aluminum-nickel-cobalt alloy (Al-Ni-Co) prepared at Ames. By precise cutting of the quasicrystal, a two-dimensional surface with one periodic axis and one aperiodic axis, separated by 90 degrees, was made.

Two scanning probe instruments were used to study the material. In the scanning tunneling microscope, a tip that tapers to a width of a single atom is drawn across a material in a manner such that the the tip never quite touches the sample atoms but is brought close enough for the electrons to begin to "tunnel" across the gap, generating an electrical current. This instrument was used to ascertain which direction was periodic and which was aperiodic. (Actually, the spacing in the aperiodic direction in this particular material was found not to be completely random. Rather it forms a Fibonacci sequence, a numerical pattern often observed in quasicrystals -- and which was one of the clues to solving the Da Vinci code in the novel by Dan Brown.) In the atomic force microscope on the other hand, the tip actually touches the sample's surface atoms as it is drawn across the material, but with so little force that none of the scanned atoms is dislodged. In this mode, the quasicrystal surface was scratched gently in each direction to measure and compare the frictional force. It was found that the friction in the periodic direction is about eight times greater than in the aperiodic direction.

The source of the difference ("anisotropy") in friction in the periodic and aperiodic directions will require more work to be fully understood. At the atomic layer, the frictional energy can be dissipated by both electronic (excitation of electrons) and by "phononic" processes (excitation of lattice vibrations or heat). It is expected to be an important theoretical challenge to determine whether electrons or phonons are the dominant contributors to the frictional anisotropy.

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Jeong Young Park, D. F. Ogletree, M. Salmeron, R. A. Ribeiro, P. C. Canfield, C. J. Jenks, and P. A. Thiel, "High Frictional Anisotropy of Periodic and Aperiodic Directions on a Quasicrystal Surface," *Science* **309**, 1354 (2005)

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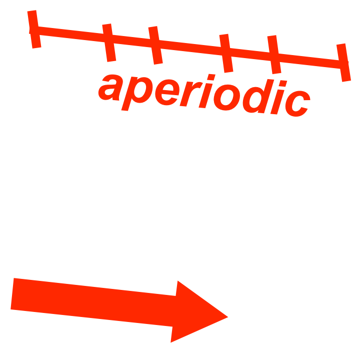


***The surface** of a Al-Ni-Co quasicrystal was prepared to create one direction with periodic atomic spacing (white arrow) and one direction with aperiodic spacing (red arrow). [In the aperiodic direction, the atomic spacing forms a Fibonacci sequence.]The friction, measured with an atomic force microscope (AFM) probe, was shown to be eight times greater in the periodic direction than in the aperiodic direction.*