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The Viscoelastic Properties of the Liquid-like Water Layer on Ice

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There has been considerable debate about the so called liquid-like (L-L) water layer on the surface of ice and its behavior as a function of temperature, a debate often aimed at the long-standing controversy over just why ice is so slippery. Here, we present the results of detailed relaxation measurements, using the Interfacial Force Microscope (IFM), in order to map the viscoelastic behavior of the L-L layer as a function of temperature from -5 to -40 °C. In these measurements, the tip approaches the surface in a series of 20 Å steps separated by pauses sufficient to allow the resulting force to relax as the liquid "drains" from the interfacial space. These measurements permit the quantitative determination of both the L-L layer thickness and its complex shear modulus both as a function of temperature and the separation between the tip and ice surface. The results indicate L-L layer thickness first by the point at which the "meniscus" initially nucleates, i.e., contact between the tip and L-L layer. Just below the freezing point, this contact appears as a sudden increase in attractive force. However, at lower temperatures the level of the increases diminishes indicating the nucleation of a "frustrated" capillary due to the increase in viscosity of the L-L layer, making it more difficult for the meniscus to spontaneously grow after initial contact. The attractive force accelerates as the tip is forced into the L-L layer until contact is made with the ice surface, where the force rapidly turns repulsive. From the details of the relaxation behavior, as the tip "steps" toward the surface, it is found that at a given temperature the viscosity increases only slightly as the tip approaches the surface after meniscus contact. In addition, after tip-ice contact, the tip is not stable and slowly creeps into the ice surface with a speed that depends on the level of the repulsive force and the temperature. The results will outline the detailed viscoelastic behavior as a function of both the temperature and the tip/ice-surface separation. In addition, they are contrasted with the behavior of the friction force, measured by dithering the tip laterally by about 20 Å at 100 Hz and detecting the lateral-force signal synchronously. These overall results give the first comprehensive picture of the L-L layer properties as a function of temperature.

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