Why honey crawls and water runs: atomistic mechanisms of viscosity in 2D fluids

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The concept of viscosity, the measure of a fluid's resistance to flow, was already known to the ancient Egyptians and can be easily experienced by simply observing a falling liquid. Yet, despite its apparent simplicity, the microscopic origins of viscosity in the dense liquid regime, where kinetic theory fails, remain poorly understood. In particular, no universally accepted formula exists that expresses viscosity directly in terms of atomic-scale dynamics. Building on Frenkel's theory of liquids and Egami's insights into the role of local atomic connectivity, we propose a simple expression that relates viscosity to a key microscopic feature of atomic motion. In essence, we argue that an atom's ability to make or lose "friends" (neighbors) is the fundamental mechanism underlying liquid viscosity. We test this formula across three distinct fluids under a range of conditions and find strong agreement with simulations. This framework also links atomic-scale dynamics with macroscopic collective modes in liquids and aligns well with the well-established Eyring equation for viscosity. Finally, we explore whether viscosity can be decomposed into "normal modes," much like the heat capacity in solids. This analysis suggests that the excitations responsible for viscosity are localized and unstable modes, a conclusion that supports earlier theoretical speculations.