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Vertical Rolling: How adhesion hysteresis enables spontaneous rolling of a soft sphere on a vertical soft wall

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ABSTRACT

On perfectly vertical surfaces, it is generally considered impossible for any known object to roll without an external torque. While nature offers intriguing examples of vertical locomotion, such as geckos and spiders, none are capable of rolling. In this study, we demonstrate that a spherical object can indeed roll on a vertical substrate without external torque when both contact pairs possess finite elasticity. As our contacting pairs, we use polyacrylamide (PAAm) spheres and polydimethylsiloxane (PDMS) substrates of tunable elasticity. Consequently, we demonstrate the spontaneous rolling of a gently dispensed PAAm sphere on a vertical PDMS substrate, at a unique elasticity combination of the materials. Making either material sufficiently softer or stiffer promotes sliding or pinning outcomes. Our experiments revealed a slow rolling motion with the sphere's center-of-mass velocity in the order of millimeters per second. Upon closer inspection, we observe that the rolling motion is induced by a dynamically changing contact diameter and a unique contact asymmetry, unlike those seen in static contacts on horizontal substrates. Using experiments and complementary theoretical modeling, we highlight how this contact asymmetry induces a pressure asymmetry that generates the necessary torque and friction to sustain continuous contact and maintain rolling. Comparison of the theoretically calculated friction force with our experimental findings yields good agreement. Beyond mere scientific curiosity, the findings illuminate new aspects of vertical surface interactions and open new avenues for exploring soft-on-soft contact systems with potential applications in soft robotics and advanced materials.