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Buckling and Mechanical Failure of Viral Shells WILLIAM S. KLUG, ROBIJN F. BRUINSMA, JEAN-PHILIPPE MICHEL, CHARLES M. KNOBLER, University of California, Los Angeles, IRENA L. IVANOVSKA, Vrije Universiteit, Amsterdam, CHRISTOPH F. SCHMIDT, Vrije Universiteit, Amsterdam, and Georg-August Universität, Göttingen, GIJS J. L. WUITE, Vrije Universiteit, Amsterdam — We present a combined theoretical and experimental study of the structural failure of viral shells under mechanical stress due to indentation by atomic force microscopy. Modeling the indentation of icosahedral viruses with two-dimensional continuum shell elasticity theory, we find that the fivefold-symmetric disclinations precipitate geometric "buckling" instabilities, leading to structural collapse at indentation loads that are significantly lower than those which buckle perfectly spherical shells. Coincident with these instabilities, discontinuities in the force-indentation curve appear when the so-called Föppl-von Kármán (FvK) number exceeds a critical value. A nano-indentation study of a viral shell subject to a soft-mode instability, where the stiffness of the shell decreases with increasing pH, confirms the predicted onset of failure as a function of the FvK number.

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