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Incompressibility, fluctuations, and elasticity in random solids[1]

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Rubbers and elastomers are usually characterized by two common properties: entropic elasticity and incompressibility. At short length-scales, these systems behave as incompressible liquids. Nevertheless, macroscopic shear deformations reduce the entropy of the polymer network, and therefore cost an elastic free energy that is proportional to temperature. In this talk I shall discuss the role of incompressibility in the elasticity of rubbery materials, and its interplay with the long wave-length fluctuations. Rubbers gain shear rigidity through the vulcanization transition, a second-order phase transition driven by cross-link density and closely related to percolation. The scaling of shear modulus as a critical phenomenon sensitively depends on the incompressibility. We have recently discovered that the vulcanization theory naturally exhibits two universality classes: phantom systems and incompressible systems. Each class exhibits distinct scaling exponent for the shear modulus near the transition. Incompressibility also crucially affects the nonlinear elasticity of rubbery materials. As we have shown recently, a subtle interplay between incompressibility and long wave-length fluctuations leads to a qualitative modification of the stress-strain relation predicted by the classical theory. To leading order, this mechanism provides a simple and generic explanation for the peak structure of Mooney-Rivlin stress-strain relation, and shows good agreement with experiments. It also leads to the prediction of a phonon correlation function that depends on the strain deformation. If time permits, I will also address incompressibility and fluctuations in liquid crystalline elastomers.

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