Nanoscale Fluid Dynamics based on the van der Waals Concept of Capillarity

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A mathematical treatment of the dynamics of liquid films on a solid substrate in general has to deal with the fact that film interface represents a free boundary whose configuration evolves both temporally and spatially. This configuration must be determined as a solution for governing equations. The most appropriate analytical method for dealing with the problem is to analyze long-scale phenomena only, in which the characteristic lateral length scale (along the substrate) is much larger than the average film thickness. Such a long-wave theory approach is widely and successfully used to model dynamics of relatively thick liquid films. However, this approach cannot be scaled directly down to the nanoscale. That is because liquid in macro and micro films is normally treated as a viscous, incompressible fluid, and Navier-Stokes equations used as the governing equations fail at the nanoscale and have to be revised.

Van der Waals attractive forces drastically change the material properties of thin liquid layers several nanometers when in contact with a solid. At this scale, the fluid is no longer homogeneous. Moreover, it has properties which analogous to those of solids. In particular, in equilibrium the stress tensor is no longer spherical. We develop a systematic continuous theory for such fluids. The Derjaguin "disjoining pressure" concept is revisited in the frame of this theory. This leads to a new model of thin film dynamics, and in particular to a new mechanism for film rupture on a substrate. The developed approach is being applied to various problems of nanoscale fluid dynamics.

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