Elasticity and plasticity : foams near jamming

Siemens, A.O.N.

Author: Siemens, Alexander Oltmann Nicolaas
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Chapter 1

Motivation: Jamming of 2D Foams

Jamming aims to describe the transition from freely flowing to rigid phases of a wide range of soft materials including foams, emulsions, suspensions and granular media [1, 2]. Over the last decade, a surge of interest in jamming has led to much progress on the theoretical understanding of the jamming transition, with a strong focus on numerical simulations [1]. While various models have been studied in simulations, most work has focused on a simple model of soft, frictionless spheres, which is thought to be a good model for foams and emulsions.

The details of the jamming scenario for these models will be reviewed in Chapter 2. For foams (and emulsions), the essence of the jamming scenario is as follows. The crucial parameter is the packing density, which for foams is measured by its gas fraction, the amount of volume taken up by the bubbles in their bounded area. Foams close to the jamming point have a low gas fraction and are said to be "wet", whereas foams that are compressed are "dry", due to a larger gas fraction in this regime. In simulations, the jamming point corresponds to the packing density at which all bubbles/particles in the packing come into contact with one another. Below this critical point, the packing is loose, with no bubbles in contact. Above the critical point the bubbles, due to their soft characteristics, are deformed. A major goal of this thesis is to probe how this scenario plays out in realistic foams.

Experimentally, foams can be studied in two different settings: in 3D and in 2D. In 3D, foams are opaque and moreover, suffer from drainage, the effect that gravity sucks the fluid out of the top layers of the foam, making it hard to maintain 3D wet foams stable in a gravitational field (recently

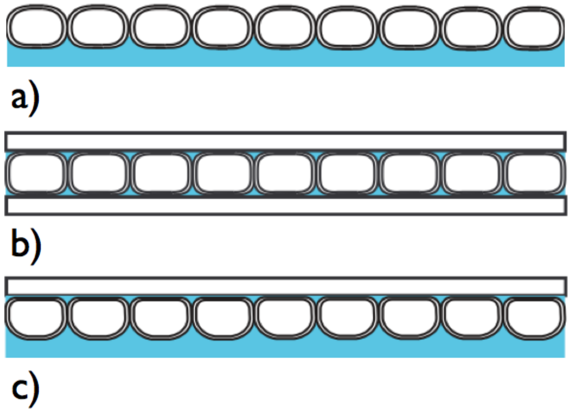

Figure 1.1 – Different bubble geometries used in two-dimensional rheology experiments: a) bubble raft, b) Hele-Shaw, c) bubble monolayer trapped between liquid surface and glass plate. Images courtesy of [6].

Isert et al. [3] managed to keep a 3D foam stable without drainage in a strong magnetic field). 2D foams do not suffer from such problems: they can be imaged easily and their packing fraction can be controlled well; in particular they can be taken close to jamming [4, 5].

These foams, monolayers of bubbles, are relatively easy to work with and recent experiments have used many different geometries, like bubble rafts [7] (no top plate bounding the packing from above, see Fig. 1.1 a)) and Hele-Shaw [8] (bubbles trapped between two glass plates, see Fig. 1.1 b)), as well as bubbles floating on a soap solution bounded from above by a glass plate [4, 5, 9, 10], see Fig. 1.1 c). This latter geometry will be used throughout this Thesis. In this configuration, the bubbles experience no appreciable attraction and interact through repulsive contact forces. There is no static friction in the system, and to avoid crystallization we use bidisperse bubbles.

In this Thesis, we probe two aspects of the mechanics of foams near the jamming transition. In Chapter 2, we introduce the concept of jamming and briefly review recent work on foams. In Chapters 3 and 4 we probe the elasticity response of foams near the jamming transition. We find that the presence of a weak symmetry breaking field, due to the residual gravity, alters the jamming scenario in an important manner; it prevents us from reaching a fully jammed state. Nevertheless, we are able to establish that near jamming, the bulk modulus is much larger than the shear modulus, which is one of the most striking theoretical predictions. In Chapter 5 we probe the plastic response of foams by submitting them to large shear deformations. We recover that the well-known plastic “T1” events dominate plastic response far away from jamming. However, closer to jamming, these T1 events give way to less strongly localized rearrangements that have not been discussed in literature, suggesting that plasticity near jamming is governed by qualitatively different and new physics.