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Liquid and solid foams / Mousses liquides et solides

## Effect of particles and aggregated structures on the foam stability and aging

*Effets des particules et des structures agrégées sur la stabilité et le vieillissement des mousses*Anne-Laure Fameau<sup>a,\*</sup>, Anniina Salonen<sup>b</sup><sup>a</sup> Biopolymères Interactions Assemblages, INRA, rue de la Géraudière, 44316 Nantes, France<sup>b</sup> Laboratoire de physique des solides, UMR 8502, Université Paris-Sud, 91405 Orsay, France

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## ABSTRACT

Aqueous foams are formed of air bubbles dispersed in a water phase. Despite the simplicity of these ingredients, the resulting foams can have an impressive range of material properties. In this review, an overview will be given on recent results obtained on the foaming properties of particles, self-assembled and aggregated structures. We will highlight how the presence of objects inside the foam can drastically modify the foam stability from unstable to ultrastable.

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## R É S U M É

Les mousses aqueuses sont formées de bulles d'air dispersées dans une phase aqueuse. En dépit de la simplicité de ces ingrédients, les mousses qui en résultent peuvent offrir une panoplie surprenante de propriétés physiques. Cet article passe en revue des résultats récents obtenus quant aux propriétés moussantes des particules, des structures auto-assemblées agrégées. On mettra en lumière comment la présence d'objets à l'intérieur de la mousse peut modifier de manière drastique la stabilité de celle-ci, d'instable à ultrastable.

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## 1. Introduction

Aqueous foams are formed of air bubbles dispersed in a water phase. Despite the simplicity of these ingredients, the resulting foams can have an impressive range of material properties. The foam can have a fleeting existence, as champagne bubbles that disappear within minutes on top of the glass. They can also be solid, yet fluid under the shear of the razor blade in shaving foam. Bubbles also transform cream to a sensual delight, by making it airy and light. In addition to these few examples foams are found in a whole range of applications: detergents, oil recovery, food, and cosmetic products [1]. The reasons for the omnipresence of foams are due to the very different properties that they can have. These properties

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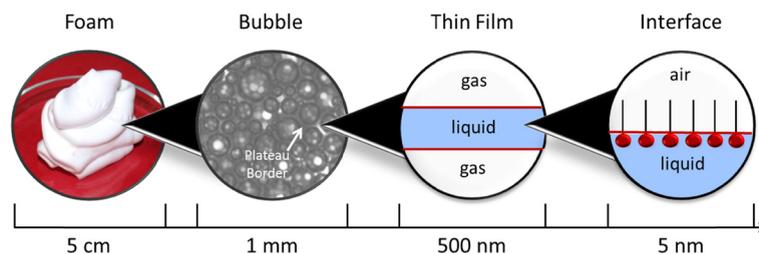


Fig. 1. (Colour online.) Foam structure at different length-scales, starting at the left at the macroscopic, and decreasing gradually down to the nanometric.

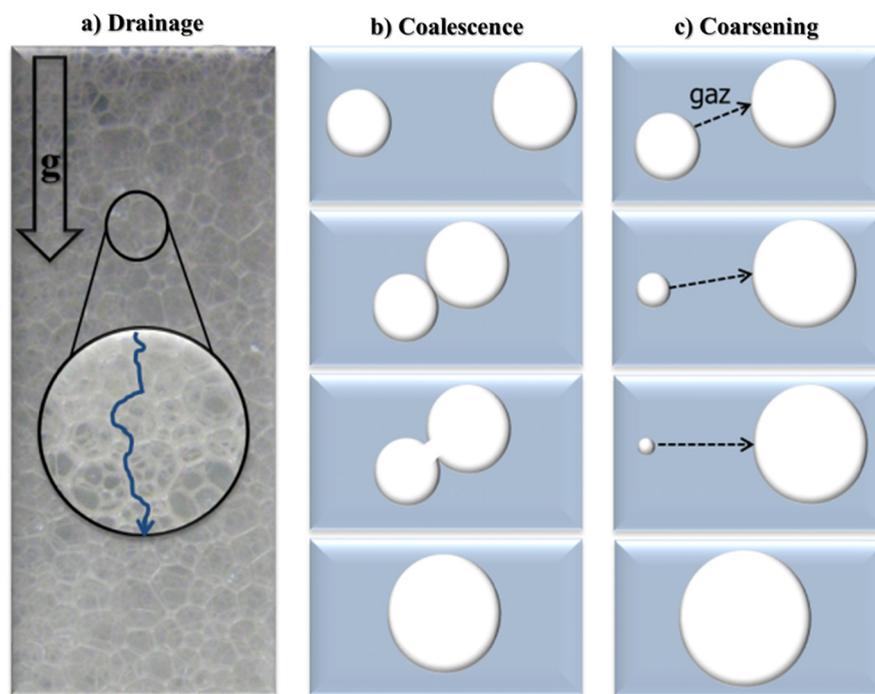


Fig. 2. (Colour online.) Scheme of the three main foam destabilization mechanisms. (a) Drainage of the liquid due to gravity, (b) coalescence of two bubbles and (c) coarsening of the bubbles due to the Laplace pressure.

are due in part to the physical properties of *bubble size* and *liquid fraction*, but even more importantly to the *physicochemical properties* of the foaming solutions. The types of objects such as molecules or particles that are used, either to adsorb onto the interfaces or to change the solution properties are endless. Indeed, the foams that can be made are only limited by our control over the physical chemistry of the foaming solutions and the understanding of the underlying physical and chemical processes that lead to foam stabilisation and destabilisation. The subject is vast. In this review we will first remind the reader of the basics of foam stability, before giving some examples of how to control their ageing using the tools of physical chemistry, especially through the use of solid particles, surfactant assemblies and protein aggregates.

**Foam structure.** Depending on the bubble size and the liquid fraction, the foam will self-organize into different structures, principally to minimize the energetically costly surface area (as discussed more in Review of W. Drenckhan and S. Hutzler). This structure spans over several length-scales starting at the molecular scale ( $\sim$  nm) and going up to the macroscopic scale (Fig. 1). The properties of the foam result from a complex coupling between them. Starting at the smallest length-scales, at the nanometer scale, there are the gas–liquid interfaces at which the adsorbed stabilizers are found. Where two interfaces are in close proximity there are thin films separating the individual bubbles. Zooming further out, at the microscopic sizes, the thin films join to create Plateau borders (PBs), which form the main liquid skeleton of interconnected channels. Looking at individual bubbles, their diameter ( $D$ ) can vary from tens of micrometres to centimetres (although in practical applications bubbles above a few millimetres are rarely found). The macroscopic scale corresponds to the whole foam, whose properties are dictated by those in all the length-scales below.

**Foam ageing.** All foams are thermodynamically unstable and disappear with time [2]. The foam is destabilised by three known mechanisms: *drainage*, *coalescence*, and *coarsening* (Fig. 2). Drainage refers to the separation of the gas and the liquid by the flow of the liquid out of the foam downward through the liquid channels due to the difference in density (Fig. 2a) [3]. Drainage lowers the liquid fraction and leads to drier foams. If the film between two bubbles is unstable it can break

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