Amoeba-like motion of an oil droplet

Chemical model of self-motile organisms

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Abstract. In this paper, we demonstrate our recent attempt to construct a chemical model system of amoeboid motion. The system is intended to mimic biological motility based on the generation and collapse of an elastic aggregate; it is composed of oil, water, and surfactants. In this chemical system, the oil–water interface shows extension and retreat of spherical extrusions accompanied by the generation of aggregate on the interface. This instability of the oil–water interface can cause autonomous splitting and motion of a floating oil droplet. The current mathematical model based on the generation of a passive elastic gel is explained, as well as the discrepancy between the model and the experiments. We further describe recently observed microscopic characteristics of the aggregate formation process that might cause the interfacial instability. Finally, we discuss the disadvantage of a chemical model system compared with active colloid and \textit{in vitro} biological systems, and also mention its potential advantages.

1 Introduction

Recent theoretical advances in active matter research have stimulated the development of experimental system in which spontaneous motion and/or collective motion can be observed. One type of approach uses simple self-propelled particles such as colloid particles [1–3] and an \textit{in vitro} motility assay [4,5]. These systems aim mainly to realize collective motion; they are starting achieve this goal thanks to modern nano- and biotechnology. Success in these approaches is necessary and even seems sufficient in order to confirm and advance research on active matter. In this discussion and debate issue, we would like to emphasize the importance of the other, intermediate and traditional, approach: the creation of biomimetic physico-chemical systems that exhibit spontaneous motion. We first discuss our attempt to generate spontaneous motion of droplets and critically consider its relevance to the research on active matter.

Self-propelled droplets have been identified and studied since the late 1970s [6]. Various types of droplet motion have been reported; their mechanism is typically based on a spatially inhomogeneous distribution of the surface tension, i.e. the

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Marangoni effect [7,8], and/or the wettability gradient [9–12]. More recently, a refined droplet system that moves under the Marangoni effect has been developed [13,14]. Despite these successes in the generation of spontaneous motion, these systems use the surface tension as the propulsion mechanism, which is quite different from biological motility. On the other hand, the generation and dissolution of an aggregate is an essential mechanism for amoeboid motion. In this paper, we introduce a physico-chemical droplet system that mimics such biological mechanisms. This chemical model system shows splitting, deformation, blebbing, and locomotion; it behaves as if it were an artificial amoeba. The present paper is organized as follows. We first present the detailed construction principle and information on the experimental setup. We then describe the typical behavior of a droplet. Theoretical considerations are then presented, and the failure of our theoretical consideration is discussed. We remark on a possible mechanism identified by a recent measurement of the aggregation formation process. Finally, we try to emphasize the relevance of the physico-chemical model system.

2 Construction of system

To make droplets that generate an elastic aggregate, we focused on a water/ionic surfactant/co-surfactant system in which the co-surfactant has a long alkyl chain (C16 to C18). These mixtures form a semitransparent gel-like aggregate and are applied in cosmetics and pharmaceutical uses as an emulsion stabilizer. They have mesoscale order and a lamellar structure with an interlayer distance of several hundreds of angstrom to 1000 Å [15–18].

The long alkyl chain co-surfactant (typically a fatty acid or an alcohol) alone is not miscible to water but is miscible to nonpolar liquids. Thus, the source of the aggregate can be dissolved into different liquid phases, that is, an aqueous phase for the ionic surfactant and an organic phase for the co-surfactant. Interestingly, both phases are isotropic liquids, but the elastic aggregate is formed in the aqueous phase when these phases are in contact with each other. Aggregate formation should be localized near the interface, and this dynamics is expected to trigger spontaneous motion of the interface. In fact, we realized interfacial motion, as well as a self-moving droplet that actively deforms, splits, and propels itself.

3 Experiment

3.1 Materials and method

STAC and palmitic acid were purchased from Tokyo Chemical Industry Co., Ltd. Tetradecane (relative density 0.76 at 20 °C) was purchased from Wako Pure Chemical Industries Ltd. Water was purified by a MilliPore Milli-Q system. The concentration of STAC in the aqueous solution is denoted as $C_s$. The organic solution was typically composed of tetradecane and palmitic acid, the concentration of which was denoted by $C_p$. If we observed that the droplet sank below the aqueous phase, we added 12 vol.% of 1,1,2,2-tetrabromoethane (relative density 2.97 at 20°C) purchased from Tokyo Chemical Industry Co., Ltd. to the tetradecane solution of palmitic acid. All measurements were made at room temperature (ca. 23°C).

3.2 Results

Immediately after an organic phase was placed in contact with an aqueous phase, the interface started to deform intensively in a Hele-Shaw-like cell, as shown in Fig. 1a [19].