Gallery of Fluid Motion

Dancing drops on lubricated surfaces

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"The manner in which aqueous vapour condenses upon ordinarily clean surfaces of glass or metal is familiar to all," so wrote Lord Rayleigh in his 1911 Nature paper [1] whimsically titled *Breath Figures*—a term now used to describe the intricate patterns that form when water vapor condenses into drops on a surface [2]. Since then, the study of condensing drops or breath figures continues to captivate the imaginations of leading scientists, including Rayleigh and Raman [3]. This fascination is fueled not only by the aesthetic beauty of these patterns but also by their significant practical applications, such as in harvesting atmospheric water and templating micro- or nanostructured materials [4].

Recently, we observed a curious breath figure pattern when water condenses on solid surfaces coated with a thin lubricant oil film. Water drops of various sizes, ranging from tens of microns to several millimetres, start to perform a self-avoiding, serpentinelike dance [Fig. 1(a)]. As the drop moves, it consumes smaller droplets along its path, converting interfacial energy into kinetic energy to sustain its motion. These self-avoiding drops preferentially avoid crossing their own paths as well as the paths of other drops [Fig. 1(b)]; they can only intersect their previous paths once sufficient recondensation has occurred. This self-avoiding behavior arises because the previous path (represented by white regions) contains little to no water content to fuel self-propulsion, so the drops continually seek areas with higher local water content (darker regions).

This intricate serpentine dance is driven by short-range interactions between droplets, mediated by overlapping menisci, similar to the Cheerios effect [5–7]. Remarkably, long-range order spontaneously emerges from these short-range interactions, with the collective motion exhibiting self-similarity—breath figure patterns appear roughly similar across different scales [compare inset and main image in Fig. 1(a)].

The serpentine motions of the drops, which can span distances many times their diameters, eventually deplete the local lubricant film, causing a transition from serpentine to circular motion (Fig. 2). This circular motion can be seen as a unique form of serpentine motion occurring in lubricant-poor regions. As the drops move, they continually redistribute the lubricant across the

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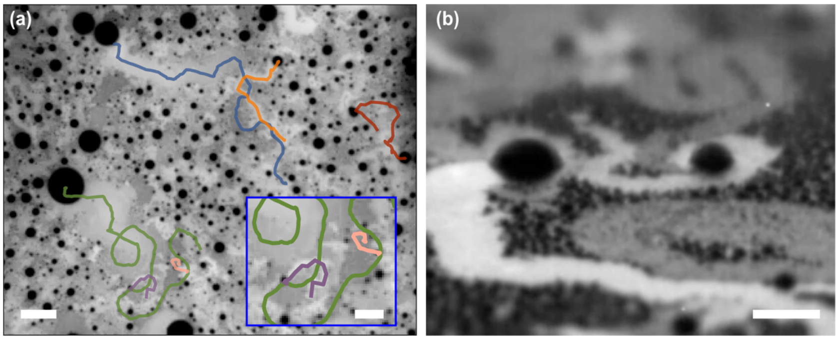

FIG. 1. Emergence of self-similar serpentine motions when drops condense on a cooled micropillar surface (hexagonal array with diameter $d = 2\,\mu$m, pitch $p = 10\,\mu$m, and height $h_p = 9\,\mu$m) lubricated with fluorinated oil (overlayer thickness $h_o = 5\,\mu$m, viscosity $\eta = 53$ mPa.s, cooled to a temperature $T = 4\,^\circ$C using a Peltier chiller). (a) Top view, scale bars are 2 mm and 1 mm for main figure and inset. (b) Side view, scale bar is 2 mm. Drops here are imaged using an infrared camera. The video associated with this image is available at https://doi.org/10.1103/APS.DFD.2023.GFM.V0030

substrate, leading to a dynamic interplay between serpentine and circular motions. This ongoing redistribution can be visualized by illuminating the surface with diffused white light and capturing the resulting interference patterns with a digital camera. Variations in lubricant thickness produce different hues, creating a vibrant, colorful canvas and an intricate dance floor for the condensing drops.

The phenomenon described in this paper represents a fascinating example of active matter driven by condensation, rather than the more commonly observed chemical reactions or Marangoni effects [8]. This work has significant potential for applications in heat transfer and water harvesting. Full details of our work can be found in our recent publication [9].

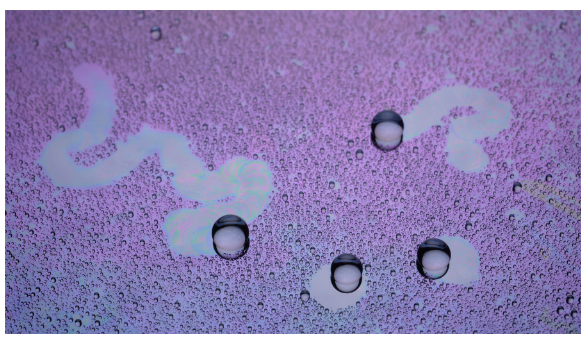

FIG. 2. As the lubricant depletes, the dancing drops transition from serpentine (top, left and right) to circular motions (bottom, right corner). The photograph, captured with a digital camera equipped with a macro lens under diffused white light, reveals colorful thin-film interference patterns. These patterns arise from submicrometric variations in the lubricant's thickness on the underlying nanostructured silicon surface.

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