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FIG. 1. (a) Side-view perspective showing the buckling instability of the crown during the water entry of a 10 mm steel sphere onto water-glycerol mixture. (b) Top-down view of the collapsing cavity. (c) Close-up view of the contact line, which is pinned around the equator of the sphere. Original video can be found online at http://dx.doi.org/10.1103/APS.DFD.2014.GFM.V0073.

Buckling instability of crown sealing

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Despite the scholarly fascination with water entry of spheres for well over a century,1 we present a new observation, namely, the crown-buckling instability. This instability is characterized by striations appearing near the top of the crown walls just prior to the surface seal, as shown in Fig. 1(a). The crown wall collapses inward due to the pressure differential across the wall created by the moving air in the wake of the sphere and surface tension within the crown. Since the rate of collapse is faster than that at which fluid drains out from the neck region, fluid collects into the striations and the crown buckles. The wall is slightly thicker along these striations than in between where the films are more susceptible to air flow and get drawn inward into the crown interior, thereby developing into bag-like structures (Figs. 1(a) and 1(b)) that ultimately atomize, causing a fine spray inside the crown. Under atmospheric conditions, this typically occurs within 5 ms after impact.

Utilizing a 6 m vacuum chamber, spheres were dropped through decreasing ambient pressures revealing that the dome over phenomenon can be significantly delayed, which in turn mitigates the buckling behavior (Fig. 2(a)). When present, however, we observe that the periodicity of the buckles can change as a function of diameter and surface tension. In particular, the number of buckles is proportional to the sphere diameter (Fig. 2(b)) but inversely proportional to surface tension (Fig. 2(c)). Surprisingly, the order of pinned contact line perturbations as shown in Fig. 1 did not correlate to the number of buckles even when their positions and number were intentionally altered (video online).
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