**Levitation of fizzy drops**

Divya Panchanathan†, Philippe Bourrianne†, Philippe Nicoller, Abhijatmedhi Chottratanapituk, Kripa K. Varanasi*, Gareth H. McKinley*

As first described by Leidenfrost, liquid droplets levitate over their own vapor when placed on a sufficiently hot substrate. The Leidenfrost effect not only confers remarkable properties such as mechanical and thermal insulation, zero adhesion, and extreme mobility but also requires a high energetic thermal cost. We describe here a previously unexplored approach using active liquids able to sustain levitation in the absence of any external forcing at ambient temperature. We focus on the particular case of carbonated water placed on a superhydrophobic solid and demonstrate how millimetric fizzy drops self-generate a gas cushion that provides levitation on time scales on the order of a minute. Last, we generalize this new regime to different kinds of chemically reactive droplets able to jump from the Cassie-Baxter state to a levitating regime, paving the way to the levitation of non-volatile liquids.

### INTRODUCTION

Liquid droplets can be levitated using various external forcing such as vibrations (1), air flows (2), acoustic waves (3), magnetic forces (4), or even their own evaporation (5, 6). A volatile liquid indeed levitates on its vapor when deposited on a very hot solid, as initially described by Leidenfrost (5). The absence of liquid-solid contact provides Leidenfrost droplets with intriguing properties such as zero adhesion, drag reduction (7, 8), extreme mobility (9–12), and thermal insulation (6, 13). However, the requisite high substrate temperature (14) limits the industrial application of Leidenfrost effects, and efforts have been made to lower the Leidenfrost temperature down to the boiling point of water (15–17). Here, we report a novel approach using supersaturated liquids to enable droplet levitation in the absence of any external forcing. We describe how carbonated water droplets deposited on a water-repellent solid can be levitated for time scales on the order of a minute at ambient temperature. Levitation occurs above a critical CO₂ concentration, an analog of the Leidenfrost temperature. This new regime of levitation exhibits similar properties to Leidenfrost droplets in terms of levitation time, antiadhesion, extremely low friction, and even self-propulsion. However, this phenomenon enables droplet levitation without requiring a specific criterion of liquid volatility. Last, we extend this concept to other gas-generating techniques based on chemically active liquids able to jump from a Cassie-Baxter wetting state to a levitating regime.

Water drops are known to be strongly repelled by superhydrophobic substrates, combining both hydrophobic chemistry and micrometric roughness (18). As seen in Fig. 1A, a drop deposited on a silicon wafer made superhydrophobic by a commercially available coating (later denoted as Glaco; see Materials and Methods and section S1) adopts a quasi-spherical shape and shows very high values of contact angles, as evidenced in the magnified view in Fig. 1C. In this so-called Cassie-Baxter state (18), the water drop sits on the tops of the hydrophobic texture (Fig. 1B), leading to a solid-liquid contact area that is reduced to a tiny fraction of its basal area. In Fig. 1D, we also observe the bottom area of a drop deposited on a transparent Glaco-coated glass substrate with an interferomicroscopy setup (see Materials and Methods and section S11). Here, the combination of dark and bright spots in Fig. 1D is the hallmark of heterogeneous wetting in the Cassie-Baxter state. However, this low-adhesion regime is metastable in many circumstances (19), and an external perturbation eventually leads to another regime (the Wenzel state) in which the liquid invades the hydrophobic porosity of the textured substrate, causing a marked increase in adhesion (19–21). Providing a lift force to promote levitation of the droplet on our substrate at ambient temperature can prevent such transitions by eliminating any local contact between the solid and the liquid drop.

### RESULTS AND DISCUSSION

**Fizzy levitation**

In this work, we propose a novel method to levitate water droplets using superhydrophobic coatings and active liquids that are able to sustain their own levitation in the absence of external stimulus. We particularly describe the case of “fizzy” water droplets that are supersaturated with dissolved gas. Here, we use the excess chemical energy stored inside the droplet in the form of dissolved gas to drive levitation instead of relying on external energy sources such as heat or mechanical motion. The chemical potential difference between the dissolved gas in the drop and the residual presence of the gas in the surrounding phase drives a mass flux from the liquid into the environment, analogous to the evaporative flux driven by a temperature difference in the Leidenfrost regime. We prepare carbonated water by pressurizing gaseous carbon dioxide into deionized (DI) water. We tune the initial CO₂ concentration C₀ by controlling the pressurization and quantify it through pH measurements (section S2). When a carbonated water drop of initial concentration C₀ ≈ 168 mM is deposited on the Glaco-coated wafer and held in place by a needle (Fig. 1E), a quasi-spherical shape is observed, equivalent to the still (uncarbonated) water in Fig. 1A. However, we can observe light passing between the drop and its reflection on the substrate similar to the original observations of Leidenfrost (movie S1) (5, 6). As shown in the magnified picture in Fig. 1G, we detect an air gap between the drop and the superhydrophobic wafer. This thin gap of thickness h ≈ 3 μm is a signature of the levitating droplet regime sketched in Fig. 1F. The released CO₂ is temporarily trapped...
underneath the drop and insulates the liquid from contacting the underlying superhydrophobic substrate. As seen in Fig. 1H, the droplet base is still circular when viewed from below but now exhibits interference fringes, a signature of levitation (22). Optical interference due to the thin gap between the top surface of the textured solid and the flattened liquid-gas interface underneath the drop produces Newton’s rings comparable to the ones observed in the Leidenfrost regime (12, 22). Our carbonated water drops thus levitate spontaneously at ambient temperature. Such levitation is in obvious contradiction with the usual observations of fizzy beverages in contact with a glass or a plastic bottle and requires a strongly water-repellent (i.e., superhydrophobic) substrate, as discussed in section S13.

However, just similar to how Leidenfrost drops vanish after a few minutes, levitation of carbonated water drops is not permanent and can be seen as a transient state on the path toward thermodynamic equilibrium. To study the temporal dependence of carbonated levitation, we observe the interface beneath our drops with an interferomicroscopy setup sketched in Fig. 2A by depositing a 40-μl carbonated water drop of initial CO₂(aq) concentration \( C_0 = 104 \pm 10 \text{ mM} \) on a transparent superhydrophobic-coated glass slide. The drops are held stationary in the field of view of the microscope by using annular rings that have been treated to make them superhydrophobic (see section S12). After initial deposition (Fig. 2B, i), we detect the interference fringes characterizing levitation (movies S2 and S3). These fringes persist for approximately 20 s, although their exact pattern evolves with time, indicating changes in both thickness and conformation of the insulating gas layer (Fig. 2B, ii). After a levitation time of \( \tau \approx 20 \text{ s} \), the liquid finally touches the superhydrophobic solid. The first contact happens at the edge of the drop \( (r = r_c \approx 0.9 \text{ mm}) \) as evident in Fig. 2B, iii. While the large gas bubble (or blister) remains at the center of the drop base, the liquid-solid contact is weak and confined to the periphery of the droplet, allowing us to define an edge-pinning transition. This contact region lastly spreads slowly inwards (Fig. 2B, iv) until it covers the entire interface (Fig. 2B, v), resulting in a distinct speckle pattern similar to the one shown in Fig. 1D for an uncarbonated water drop in the Cassie-Baxter state on a superhydrophobic solid (movie S3) and sharply contrasting with the levitating regime. We can thus define the wetting time \( \tau^* \) at which the carbonated water drop enters a regular Cassie-Baxter state (here, \( \tau^* \approx 95 \text{ s} \)). Whereas Leidenfrost drops finally vanish because of their complete evaporation, these carbonated water drops persist even after levitation is complete.

To obtain a closer look at the dynamics of levitation, we study the profile of the gas-liquid interface underneath the drop. As reported in the Leidenfrost regime (12, 22) and predicted in the general case of levitating drops (23), the underside of these levitating fizzy drops is curved because of the formation of a central dimple (with radius of curvature \( R_b \)) that seeks to rise due to buoyancy (Fig. 2A) (6). The thickness of the gas layer reaches a minimum value \( h \) at the edge of the base \( (r = r_c) \) and is maximal at the center of the droplet \( (z = h + H_b) \) at \( r = 0 \), with \( H_b \) as the height of the dimple. At the end of the levitation regime \( (t > \tau) \), because of the edge-pinning transition, a blister (also defined by \( H_b \) and \( R_b \)) is observed, as shown in Fig. 2B (iii). Using interferomicroscopy, we image successive fringes as seen in Fig. 2B, allowing us to extract the evolution in the relative height \( \delta(r) \) of the interface underneath our drop \( \delta(r) = z(r) - h \) (section S4). Moreover, as discussed later, the minimum thickness \( h \) can also be estimated (section S5), enabling us to determine the absolute height of the gas-liquid interface \( z(r) \). In Fig. 2C, we report the profile \( z(r) \) of the drop in the levitating regime \( (t < \tau = 20 \text{ s}) \). The symbols represent our measurements, while the solid lines are obtained by fitting the central bubble profile by a

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**Fig. 1. From the Cassie-Baxter state to drop levitation.** (A) Photograph of a 40-μl water drop held by a needle on a superhydrophobic wafer. Scale bar, 2 mm. (B) Sketch (not to scale) of a millimeter-sized drop (radius \( R \) and contact radius \( r_c \)) of water in the Cassie-Baxter state. (C) Zoomed picture of the bottom edge of a 40-μl drop in the Cassie-Baxter state with an apparent contact angle \( \theta_2 = 167^\circ \). Scale bar, 100 μm. (D) Bottom view of a 40-μl deionized (DI) water drop deposited on a transparent Glaco-coated glass slide using interferomicroscopy. Scale bar, 500 μm. (E) Picture of a 60-μl carbonated water drop (\( C_0 = 168 \text{ mM} \)) held by a needle on a Glaco-coated wafer. A thin ray of light is noticeable between the drop and its reflection. Scale bar, 2 mm. (F) Sketch (not to scale) of a millimeter-sized drop of carbonated water releasing CO₂ and levitating over a thin cushion of gas of thickness \( h \) (not to scale) of a millimeter-sized drop (radius \( R \) and contact \( r_c \)) of water in the Cassie-Baxter state. (G) Sketch (not to scale) of a millimeter-sized drop of carbonated water releasing CO₂ (not to scale) of a millimeter-sized drop (radius \( R \) and contact \( r_c \)) of water in the Cassie-Baxter state. (H) Bottom view of a 40-μl carbonated water drop deposited on a Glaco-coated glass slide. Interference fringes indicate complete levitation as reported in the classical Leidenfrost regime (12, 22). Scale bar, 500 μm.
quadratic shape, in good agreement with the spherical cap approximation \( z \approx h + H_b - r^2/(2R_b) \) with \( H_b \ll R_b \). The profiles in Fig. 2C exhibit a clear evolution from a bubble height of around 8 \( \mu \)m at \( t = 8 \) s after deposition (red data) to a value reduced by a factor of three after 20 s (pink triangles). Moreover, the quadratic fit gives us an estimation of both geometrical parameters of the bubble (\( H_b \) and \( R_b \)). The evolution of the two parameters are coupled together and are inversely proportional in the levitating regime when the contact radius \( r_c \) of the drop is constant: \( H_b \approx r_c^2/(2R_b) \). As predicted for a millimetric-scale drop (23), the height \( H_b \) of the central bubble is small (on the order of a few microns) compared to \( r_c \). In Fig. 2D, we report the variation in \( R_b \) (as estimated by the quadratic fit) with time \( t \). The radius of curvature \( R_b \) of the central bubble underneath the dimpled drop is initially \( \approx 25 \) mm shortly after the drop deposition, which indicates small yet measurable curvature. As time progresses, \( R_b \) increases rapidly, leading to a decrease of curvature, i.e., the interface flattens. The gas entrapped underneath the drop drains out of the thin gap. The dimple radius of curvature finally reaches a maximum value of about \( R_b \approx 150 \) mm at the levitation time \( t \rightarrow \tau = 20 \) s. At this critical time, \( R_b \) experiences a sharp and sudden decrease. In less than a second, the radius of curvature of the central bubble decreases by a factor of four to regain its initial value; this is due to the progressive appearance of contact points between the liquid and the solid at the edge of the drop base (\( r = r_c \)). This edge-pinning transition leads to a reduction in the number of pathways for the gas exiting the liquid and an increase in pressure within the dimpled vapor bubble. Consequently, the apex height \( H_b \) of the bubble rises and the radius of curvature \( R_b \) decreases at the end of levitation (section S6). These sharp transitions allow us to precisely define the value of levitation time \( \tau \).

The levitating regime (red area in Fig. 2D) is followed by a longer second regime (\( \tau < t < \tau^* \)) in which a pinned blister is still present below the drop (purple frame in Fig. 2D), allowing partial levitation in which limited contacts between solid substrate and liquid drop exist but are reduced compared to the Cassie-Baxter state. The shape of this bubble can also be measured by interferometry and is plotted in Fig. 2E. The blister height is initially around 10 \( \mu \)m at \( t = 23 \) s but decreases slowly down to \( \approx 3 \) \( \mu \)m after 90 s. In this partially levitating regime, the gas trapped after touchdown initially accumulates in a bubble whose profile can also be fitted by a quadratic shape. However, over time, the trapped gas eventually flows through the porosity of the superhydrophobic coating, in a similar manner to previous reports on warm superhydrophobic solids in the presence of vapor patches partially covering the drop basal area (17). The volume of the blister then decreases slowly and irreversibly, leading to a noticeable decrease in \( H_b \) as captured in Fig. 2E. Similarly, the radius of curvature of the bubble (\( R_b \)) increases slowly over time during the blister regime indicated in Fig. 2D (purple shading). As liquid-solid contacts spread radially inwards from the edges to the center of the drop base, we reach the Cassie-Baxter state at time \( \tau^* \) when no gas blister remains. This fizzy levitation process at ambient temperature not only allows us to preserve the volume of the drop at the end of levitation (light blue area, \( t > \tau^* \) in Fig. 2D) but also leads to an intermediate regime of lower adhesion (\( \tau < t < \tau^* \)).
However, the dynamics of the levitation is affected by the concentration $C_0$ of CO$_2$ dissolved in the droplet. By visualizing the drop basal area using the interferomicroscopy setup, we do not observe levitation below a critical concentration of CO$_2$ denoted as $C_l$, an analog of the critical Leidenfrost temperature $T_l$. The onset of levitation reported in Fig. 3A appears to be set by a critical CO$_2$ concentration $C_l \approx 7 \pm 3$ mM. Using Henry’s law with a constant $k_H = 3.6 \times 10^{-2}$ mM/atm (24), this leads to an equivalent partial pressure $P_l = C_l/k_H \approx 0.2$ atm, i.e., somewhat smaller than atmospheric pressure $P_0$. However, CO$_2$ is released from carbonated droplets at even smaller initial saturations because the atmospheric partial pressure of CO$_2$ is typically $\sim 3 \times 10^{-4}$ atm (25). This indicates the necessity to reach high initial levels of gas saturation in our drop to provide levitation, a similar constraint as observed in the Leidenfrost regime, where drop levitation is only triggered in a superheated regime far above the typical evaporative limit (i.e., $T_l$ is always larger than the boiling point of the liquid) (14, 15, 17).

Below the critical concentration $C_l$, gas is still released from the saturated drop and eventually leads to a partial levitation (depicted in purple in Fig. 3A). As better seen in the inset pictures of Fig. 3A, the drop base can sustain multiple gas blisters spreading laterally across the superhydrophobic, or “superaerophilic” (26), solid. However, these gas patches do not span the entire drop base and fail to provide complete levitation. This partial regime acts as a transitional behavior between a Cassie-Baxter state below $C_l$, an analog of the critical Leidenfrost temperature $T_l$, and the superhydrophobic, or “superaerophilic” (26), solid. However, these gas patches do not span the entire drop base and fail to provide complete levitation. This partial regime acts as a transitional behavior between a Cassie-Baxter state below $C_l$, an analog of the critical Leidenfrost temperature $T_l$, and the superhydrophobic, or “superaerophilic” (26), solid.

The key parameter mediating droplet levitation is the minimum thickness $h$ of the gas layer. By using the interferomicroscopy setup sketched in Fig. 2A, we can measure $h(t)$ by focusing on the edge of the drop base ($r = r_c$) and counting fringes, while $h(t)$ decreases continuously until touchdown (see section S5 and movie S4). The time dependency of $h$ is discussed in more detail in section S7; here, we focus on the initial thickness $h_0$ of the gas layer. In Fig. 3B, we report values for $h_0$ as a function of the initial dissolved CO$_2$ concentration ($C_0$) as determined by pH measurements. As noted above, no levitation is observed below a critical concentration of CO$_2$ denoted as $C_b$, an analog of the critical Leidenfrost temperature $T_b$. The thickness of the initial gas layer is measured above $C_l$ and shows a monotonic increase with the initial concentration $C_0$. In the levitating regime (above $C_l$), the initial thickness of the insulating film rises from around 500 nm at $C_0 \approx 30$ mM to more than 3 $\mu$m when $C_0 = 170$ mM.
provide understanding of this apparent contradiction. The thin gas layer is pressurized by the drop (either because of its weight $\Delta P \sim g \rho H$ or the Laplace pressure $\Delta P \sim \gamma/R$), leading to a radial Poiseuille flow in the underlying gas film with velocity field $U(r, z)$, similar to classical laws in Leidenfrost regime (6, 27). By assuming a uniform thickness for simplicity, a lubrication approximation allows us to solve analytically for this incompressible vapor flow, and we determine an average velocity that scales as $U \sim \Delta P h^2/\eta_g r_c$ with $\eta_g$ as the viscosity of $\mathrm{CO}_2(g)$ and $r_c$ as the size of the drop base. A mass balance in the vapor layer states that the release rate $m$ scales as $m \sim \rho_g r_c h \bar{U}$ with $\rho_g$ as the density of $\mathrm{CO}_2(g)$. Combining these two equations, we can deduce the scaling $m \propto h^3$. For a carbonated water drop, the available fuel driving fizzy levitation is limited by the molar quantity of $\mathrm{CO}_2(aq)$ dissolved in volume $\Omega$ [i.e., $(\Omega C_0) \approx 4 \mu\text{mol}$ for a 40-$\mu\text{L}$ carbonated droplet with an initial concentration of $C_0 \approx 0.1 \text{ M}$]. This value is lower by three orders of magnitude than that for a classical Leidenfrost drop in which the whole liquid phase evaporates ($\Omega \rho_l/\rho_{\text{H}_2\text{O}} \approx 2 \text{ mmol}$ for a 40-$\mu\text{L}$ drop with $\rho_{\text{H}_2\text{O}} = 18 \text{ g/mol}$). The similar values of evaporation time scales in both phenomena thus suggest a gas release rate $m$ that is three orders of magnitude lower in the case of a fizzy droplet. While Leidenfrost drops experience rapid vapor flow in the gas cushion dominated by convection in the vapor cushion (27), the slow $\mathrm{CO}_2$ release rate around a levitating carbonated drop is controlled by diffusion in a mass boundary layer (see section S8). In consequence, as $m \propto h^3$, the thickness of the gas cushion adapts and decreases by one order of magnitude in good agreement with the measurements in Fig. 3B.

**Applications of fizzy levitation**

In Fig. 4, we investigate the dynamics of these levitating objects. Because the gas cushion insulates the drop from the underlying textured substrate, sliding friction is markedly reduced. In Fig. 4B, a drop is released at the rim of a superhydrophobic-coated trough of constant curvature (see Materials and Methods) sketched in Fig. 4A. While the DI water drop oscillates only twice about the center of the groove (Fig. 4B, i), carbonated drops at higher $\mathrm{CO}_2(aq)$ concentrations ($C_0 \gg C_l$) exhibit a larger number of damped oscillations, demonstrating substantially enhanced mobility due to smaller friction (28). By tracking the drops, we extract the time-dependent position $\theta(t)$ of the drop in Fig. 4C. We observe a damped harmonic oscillator behavior for different initial concentrations of $\mathrm{CO}_2$. The period of oscillations is not affected by $C_0$ with a constant value about 1.6 s, a value in good agreement with the pendulum analogy ($\omega = \sqrt{g/R_g} \approx 4 \text{ rad/s}$; see section S9). However, the damping coefficient varies markedly between low $\mathrm{CO}_2$ concentration (blue symbols) and larger concentrations (red symbols). The number of oscillations increases with the initial $\mathrm{CO}_2$ concentration, indicating that the low value of the friction coefficient for a water drop on a superhydrophobic coating becomes even smaller with carbonated water; the released $\mathrm{CO}_2$ vapor insulates the drop from discrete pinning events on the randomly textured substrate. By considering viscous dissipation in the gas cushion during the levitating regime, we can capture the damped periodic oscillations in the measured position $\theta(t)$ and extract values for the dynamic gas film thickness (typically a few microns), which are in good agreement with the interferometric measurements shown in Fig. 3B (see section S9). The levitation of fizzy fluids thus results in dynamic properties analogous to Leidenfrost droplets in terms of reduction of sliding friction.

**Thermally levitating Leidenfrost drops**

Thermally levitating Leidenfrost drops have also been shown to self-propel on substrates featuring millimetric-scale machined textures (9). Volatile drops placed on hot ratchet substrates propel in a given direction due to the viscous entrainment of the asymmetric vapor-insulating layer that imposes a net lateral force on the drop. We machined a brass ratchet with asymmetric teeth of pitch $\lambda = 1.5 \text{ mm}$ and height $\epsilon = 0.3 \text{ mm}$. When a 300-$\mu\text{L}$ carbonated drop ($C_0 = 97 \text{ mM}$) is deposited on the ratchet, we observe a redirection of the drop in the direction of the ratchet teeth (movie S6). The drop self-propels (from left to right) with a steady terminal velocity of around 15 mm/s, a value 10 times smaller than the traditional Leidenfrost case (10) but yet comparable to the “cold” Leidenfrost regime recently observed on warm superhydrophobic substrates (29). This decrease in the propulsion velocity arises from the reduced thickness of the gas layer in our room temperature regime and the concomitant increase in the vapor phase friction.

We can also generalize this vapor-mediated technique to incorporate other “chemically active” drops able to generate their own levitation. In this paper, we have focused on the case of carbon dioxide dissolved in water at room temperature. We can easily dissolve other gases of even higher solubility. We can also use chemical...
sitting in the Cassie-Baxter state on a Glaco-coated glass slide (i). The generation of CO$_2$(g) leads to the formation of bubbles (ii) and, ultimately, to the levitation of hydrogen peroxide H$_2$O$_2$ (9.8 M) is added to the first drop. As po-

\[ \text{CO}_2(g) \rightarrow \text{CO}_2(s) \]

exhibiting a Cassie-Baxter state. In Fig. 5B (ii), a 10-

\[ \mu \text{L} \]

drop of an aqueous solution of potassium iodide (at an initial concentration of [KI] = 0.18 M) resides on the superhydrophobic substrate in a Cassie-Baxter state jumps into a state of levitation. This gas is then released and leads to the formation of bubbles that spread across the superhydrophobic coating (Fig. 5A, ii) and eventually merge, leading to levitation (Fig. 5A, iii, and movie S7). Experiments show that this self-levitation of chemically reactive liquids also requires a large enough rate of release of CO$_2$(g) vapor and a superhydrophobic substrate (section S1). Moreover, other gases, such as O$_2$ in Fig. 5B, can also provide levitation. When a 10-\(\mu\)L drop of an aqueous solution of potassium iodide (at an initial concentration of [KI] = 0.18 M) resides on the superhydrophobic transparent surface in Fig. 5B (i), it sits on the top of the texture exhibiting a Cassie-Baxter state. In Fig. 5B (ii), a 10-\(\mu\)L drop of hydrogen peroxide H$_2$O$_2$ (9.8 M) is added to the first drop. As potassium iodide catalyzes the decomposition of hydrogen peroxide into a drop of an aqueous solution of potassium iodide (10 \(\mu\)L, [KI] = 0.18 M), O$_2$(g) is generated and levitation is again eventually achieved. Scale bars, 0.5 mm. (C) Carbonated water (C$_t$ = 168 mM) in a wine glass treated with Glaco coating on one half (right) and untreated on the other half (left). Similar to the Leidenfrost effect, we observe the difference between “nucleate boiling” on the hydrophilic surface (left) and film boiling on the superhydrophobic glass (right). Photo credit: D. Panchanathan and P. Bourrianne, MIT.

**Fig. 5. Generality of fizzy levitating drops.** (A) A 20-\(\mu\)L drop of sodium bicarbonate (0.5 M) is deposited on the top of a droplet of hydrochloric acid (20 \(\mu\)L, 0.5 M) initially sitting in the Cassie-Baxter state on a Glaco-coated glass slide (i). The generation of CO$_2(g)$ leads to the formation of bubbles (ii) and, ultimately, to the levitation of the entire drop (iii). (B) When mixing a drop of hydrogen peroxide (10 \(\mu\)L, [H$_2$O$_2$] = 9.8 M) into a drop of an aqueous solution of potassium iodide (10 \(\mu\)L, [KI] = 0.18 M), O$_2$(g) is generated and levitation is again eventually achieved. Scale bars, 0.5 mm. Carbonated water (C$_t$ = 168 mM) in a wine glass treated with Glaco coating on one half (right) and untreated on the other half (left). Similar to the Leidenfrost effect, we observe the difference between “nucleate boiling” on the hydrophilic surface (left) and film boiling on the superhydrophobic glass (right). Photo credit: D. Panchanathan and P. Bourrianne, MIT.

**MATERIALS AND METHODS**

### Superhydrophobic coating

Our Glaco coating is prepared with a colloidal solution, Glaco Mirror Coat Zero purchased from Soft99 Co. (Japan). The deposited solid films drawn out of the Glaco dispersions are postbaked at 250°C for 30 min, a process repeated three times to provide a homogeneous coating with minimal pinning points (section S1). Advancing and receding angles of water at ambient temperature are, respectively, $\theta_a = 169^\circ \pm 2^\circ$ and $\theta_r = 165^\circ \pm 2^\circ$, which leads to a very low contact angle hysteresis $\Delta \cos \theta = \cos \theta_r - \cos \theta_a = 10^{-2}$.

### Concentration of CO$_2$(aq)

Carbonated water was prepared by pressurizing gaseous carbon dioxide into DI water at ambient temperature. Commercially available polyethylene terephthalate bottles (purchased from Poland Spring) were closed with a carbonation cap (Ferroday) and connected to a gas line (CMB Becker), which delivers carbon dioxide from a CO$_2$ tank (Airgas) under constant CO$_2$ pressure delivered by a CO$_2$...
pressure regulator (Airgas/Harris). The initial concentration $C_0$ of CO$_2$(aq) dissolved in water was estimated by immersing a micro pH electrode (Thermo Scientific Orion) as described in section S2. The volume of the drops was also carefully calibrated (section S10).

**Interferomicroscopy setup**

The base of drops was imaged using a 4× objective mounted on an inverted microscope (Nikon Eclipse TE2000-U) connected to a digital camera (GH5 Lumix). Illumination was provided via a filter cube consisting of a semireflective mirror, a filter ($\lambda = 542 \pm 15$ nm) for the incident light, and no filter for the emitted/reflected light. The drops were kept stationary in the field of view of the microscope by trapping them with superhydrophobic annular rings (see section S12).

**Measurement of the gas thickness**

The measurement of the minimum gas thickness $h$ at the rim was obtained after imaging the edge of the drop base with a 20× objective mounted on the inverted microscope and connected to a high-speed camera (Phantom Miro 320S). Successive interference fringes were counted to back-calculate the evolution in the minimum gas film thickness $h(t)$ at the edge of the levitating drop (movies S4 and S5). The initial thickness $h_0$ was reported after the stabilization of the interface, while the reading remains roughly constant for a few seconds.

**Trough**

The trough (of radius of curvature $R_g = 635$ mm and of length $L_g = 65$ mm, i.e., a slope < 6°) sketched in Fig. 4A was machined in aluminum. Experiments were carried out by capturing top views with a high-speed camera (Phantom Miro 320S). To prevent any lateral motion of the drop, we added a secondary curvature in the orthogonal direction of the motion.

**SUPPLEMENTARY MATERIALS**

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/7/28/eabb0888/DC1

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project. D.P. and P.B. designed and analyzed the experiments. D.P., P.B., P.N., and A.C. performed the experiments. D.P., P.B., and G.H.M. wrote the manuscript with inputs from K.K.V. D.P. and P.B. have equally contributed to this work. Competing interests: The authors declare that they have no competing interests. Data and materials availability: All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials. Additional data related to this paper may be requested from the authors.

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Gareth H. McKinley

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