How a drop removes a particle from a hydrophobic surface: Supplementary Information

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(Dated: December 4, 2020)

1. Force measurements

The spring constant of the blade was determined from its natural frequency. The lower end of the blade was displaced by a small amount from its equilibrium position. The subsequent oscillations were recorded with the microscope, and the frequency, f, of the oscillations was determined. The spring constant can be obtained from this frequency using the relation $k = 0.243m\omega^2$[1], where m is the mass of the part of the blade that is hanging freely, and $\omega = 2\pi f$. The pre-factor (0.243) accounts for the fact that the mass is uniformly distributed throughout the blade.

Systematic errors

Using this method, the maximum fractional uncertainty in spring constant is

$$\frac{\Delta k}{k} = \frac{\Delta m}{m} + 2\frac{\Delta f}{f}. \tag{S1}$$

The uncertainty in the frequency is determined by the time resolution ΔT of the microscope according to $\Delta f/f = \Delta T/T$. The mass of the freely hanging length l was obtained by measuring the total mass, M, and the total length, L, of the blade, then using $m = Ml/L$. Including these considerations in Eq.S1 gives

$$\frac{\Delta k}{k} = \frac{\Delta M}{M} + \frac{\Delta L}{L} + \frac{\Delta l}{l} + 2\frac{\Delta T}{T}. \tag{S2}$$

The uncertainty in the determination of mass (measured with an electronic balance) is $\Delta M/M \approx 0.1$ mg/72.3 mg $= 0.1\%$. Using a digital vernier calliper, the fractional uncertainty in l was $\Delta l/l \approx 0.2\%$. The natural frequency was 11.7 Hz, corresponding to a fractional uncertainty in the time period of $\Delta T/T = (0.0014/15)/0.0854 \approx 0.1\%$. Therefore, the fractional uncertainty in the spring constant is

$$\frac{\Delta k}{k} \approx 0.1\% + 0.2\% + 0.2\% + 2(0.1\%) \approx 1\%.$$

This uncertainty in the spring constant, $k = (0.057 \pm 0.001)$ N m^{-1}, translates to an uncertainty in the measured force of

$$\frac{\Delta F}{F} = \frac{\Delta k}{k} + \frac{\Delta(\Delta x)}{\Delta x} \approx 1\% + \frac{3}{700} \times 100 \approx 2\% \tag{S3}$$

Here, $\Delta(\Delta x/x)$ is the fractional uncertainty in measuring the blade deflection in a typical measurement. $\Delta(\Delta x)$ is given by the pixel size ($\approx 3\ \mu$m) and Δx is the size of a typical deflection ($\approx 700\ \mu$m).

The spring constant determined using the above method is valid if the force is applied precisely at the bottom edge of the blade of length l. When pushing drops, the force, F_{drop}, acting on the blade is not localised at the edge, but is distributed over circular/elliptical segment. Consequently, the moment produced by the force about the clamped end is smaller than if the same force was localised at the bottom edge. Therefore, the apparent force measured by the blade when the force is centred at a distance h above the bottom edge is $F_{\text{app}} = F_{\text{drop}}(l-h)/l$. This effect introduces an additional error (in addition to the 2% calculated in Eq. S3) in the force measurements:

$$\frac{\Delta F}{F} = \frac{h}{l} \approx \frac{1\ \text{mm}}{50\ \text{mm}} = 2\% \tag{S4}$$

Here, we have taken h to be approximately equal to the radius of a typical drop used in the experiments. Note that this effect will lead to a measured force that is systematically lower than the actual force acting between the drop and the surface. However, the extent of this error is not significant for this study. By adding all the uncertainties discussed above, the total systematic uncertainty is $\approx 2\% + 2\% = 4\%$. For a force of $\approx 50\ \mu$N [Fig. 2(d)], this corresponds to an error of $2\ \mu$N.

Random errors

In addition to the systematic errors mentioned above, there will also be random errors due to ambient vibrations and air drafts in the vicinity of the setup. We quantified the random fluctuations by measuring the fluctuations of a freely handing blade [Fig. S1 (a)]. The standard deviation was $0.1\ \mu$N, which is negligible compared to the force caused by surface inhomogeneities, as shown by the reproducible fluctuations in Fig. S1 (b). Therefore, the random noise due to ambient vibrations can be ignored for the purpose of this study.

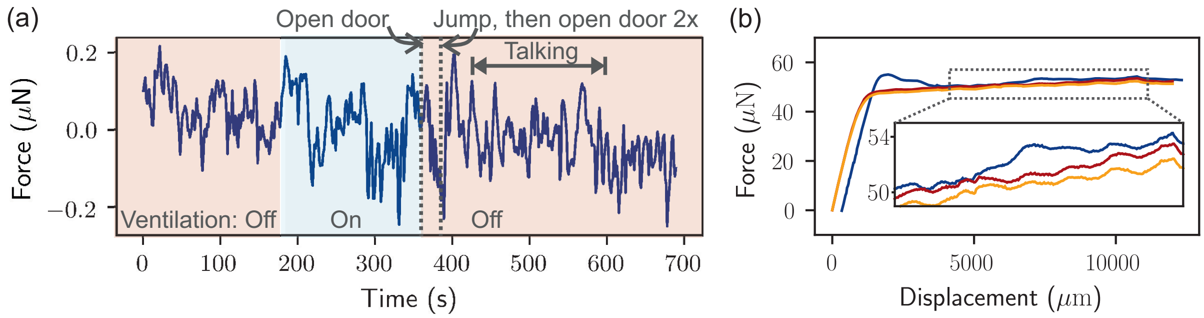

FIG. S1. (a) Noise level under various conditions. (b) Force to push a 3 μL water drop on PDMS surface at 500 μm s^{-1} along the same track three times. Blue, red and orange curves correspond to first, second and third runs, respectively. The time between the start of each run was $\approx$ 75 s. The blue curve has an initial maximum, when the drop's interface still corresponds to pure water. As the drop accumulated uncrosslinked PDMS molecules from the surface, the force decreased to a steady value [2]. The slight decrease in force between successive runs is due to drop evaporation. The inset shows that the fluctuations in the force are very similar for the red and orange curves, demonstrating that they originate from surface inhomogeneities. The first run (topmost, blue curve) showed worse agreement since the drop had to partially clean the substrate during the first run.

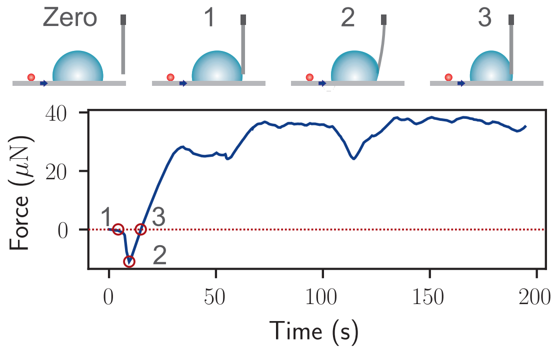

FIG. S2. Full force-time curve corresponding to a drop-particle collision on a PDMS surface at 50 μm s^{-1}. Initially, the blade hung freely, corresponding to a zero force. At point 1, the blade jumped into contact with the blade (snap-in). Only experiments where the drop and blade are not initially in contact have this feature. For repeat experiments using the same drop, there is no drop-blade snap-in since they are already in contact. Therefore, the snap-in of the blade with the drop has been omitted in the force curves presented throughout the paper. All the force curves presented start at point 3.

[1] H.-J. Butt, B. Cappella, and M. Kappl, Surf. Sci. Rep. **59**, 1 (2005).

[2] A. Hourlier-Fargette, A. Antkowiak, A. Chateauminois, and S. Neukirch, Soft Matter **13**, 3484 (2017).