18.357: Lecture 15

Contact angle hysteresis,

The wetting of textured solids

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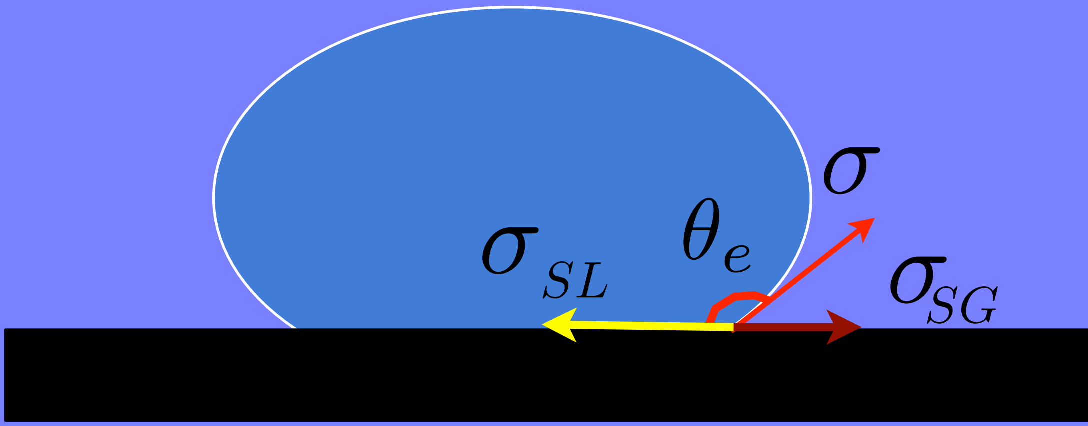
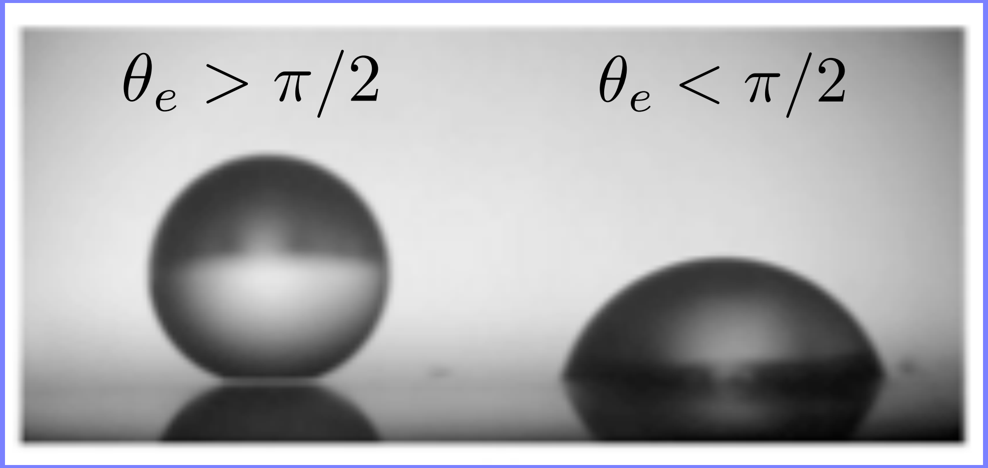
Fluid-Solid Contact: WETTING



Equilibrium contact angle θ_e

Energy differential: $dW = dx\,(\sigma_{SG} - \sigma_{SL}) - dx\;\sigma\;cos\theta_e$

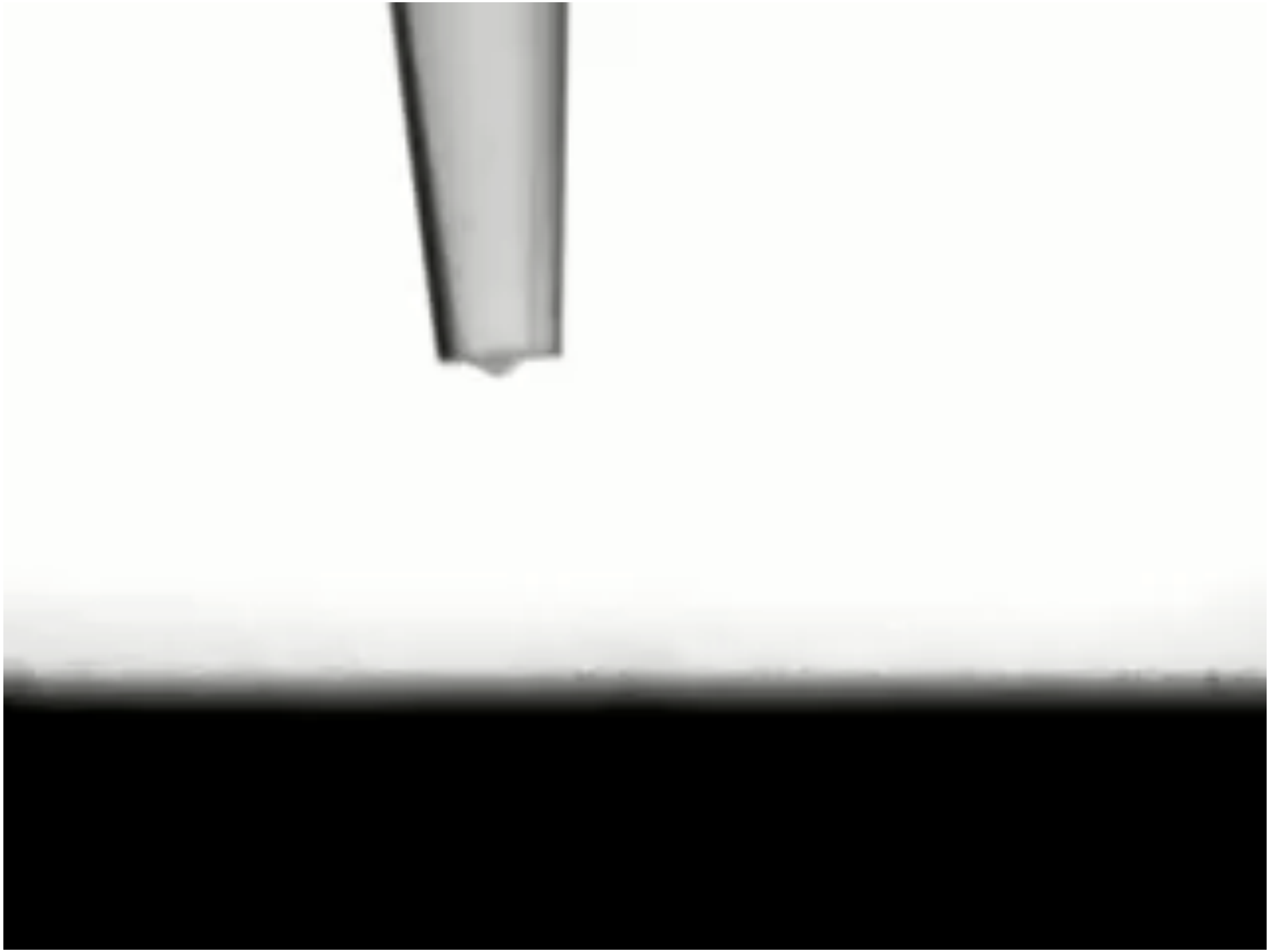
Young's relation: $\sigma\;\cos\theta_e = \sigma_{SL} - \sigma_{SG}$



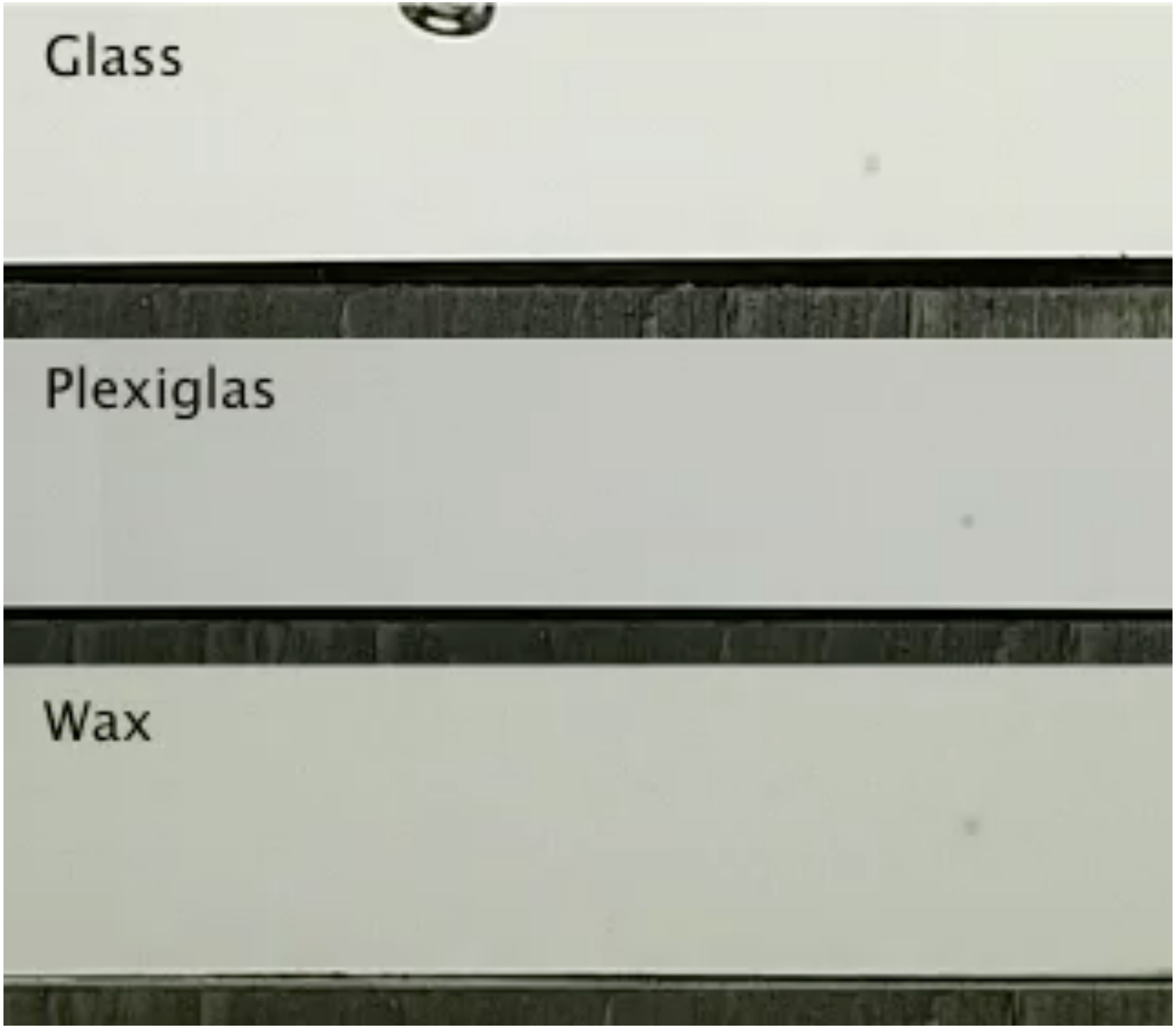
Hydrophobic surface

Hydrophilic surface

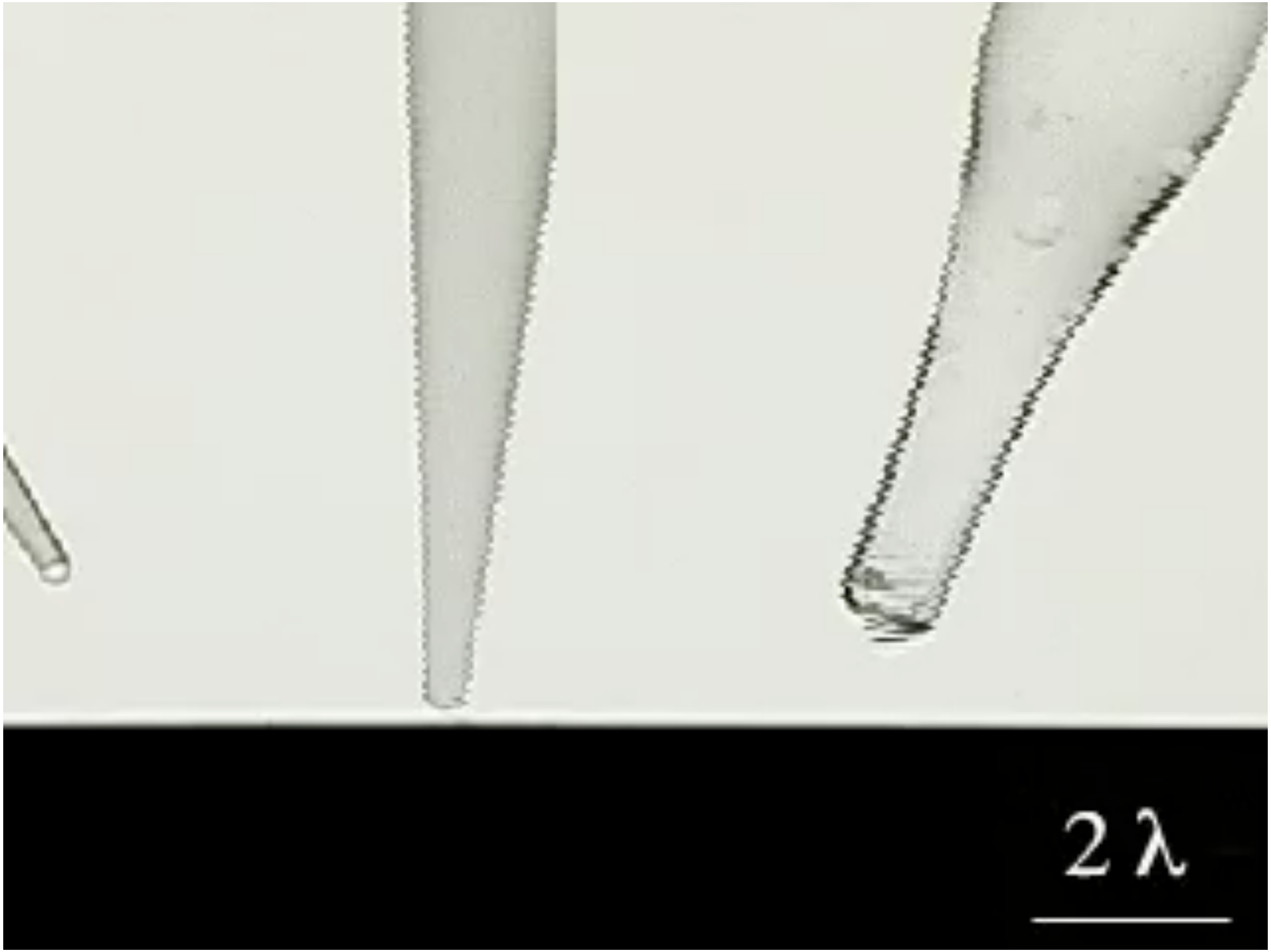
Total wetting on a flat solid

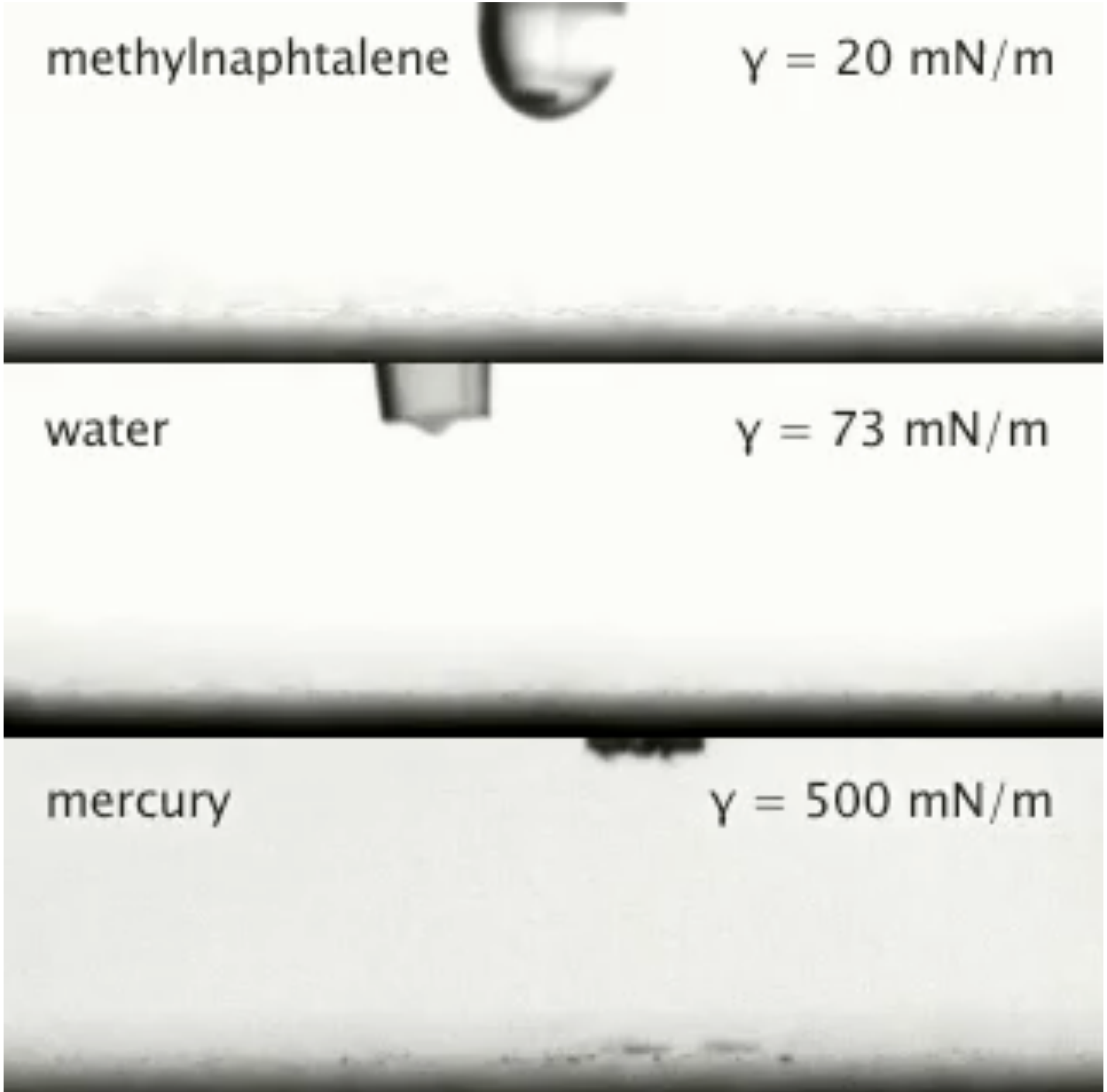


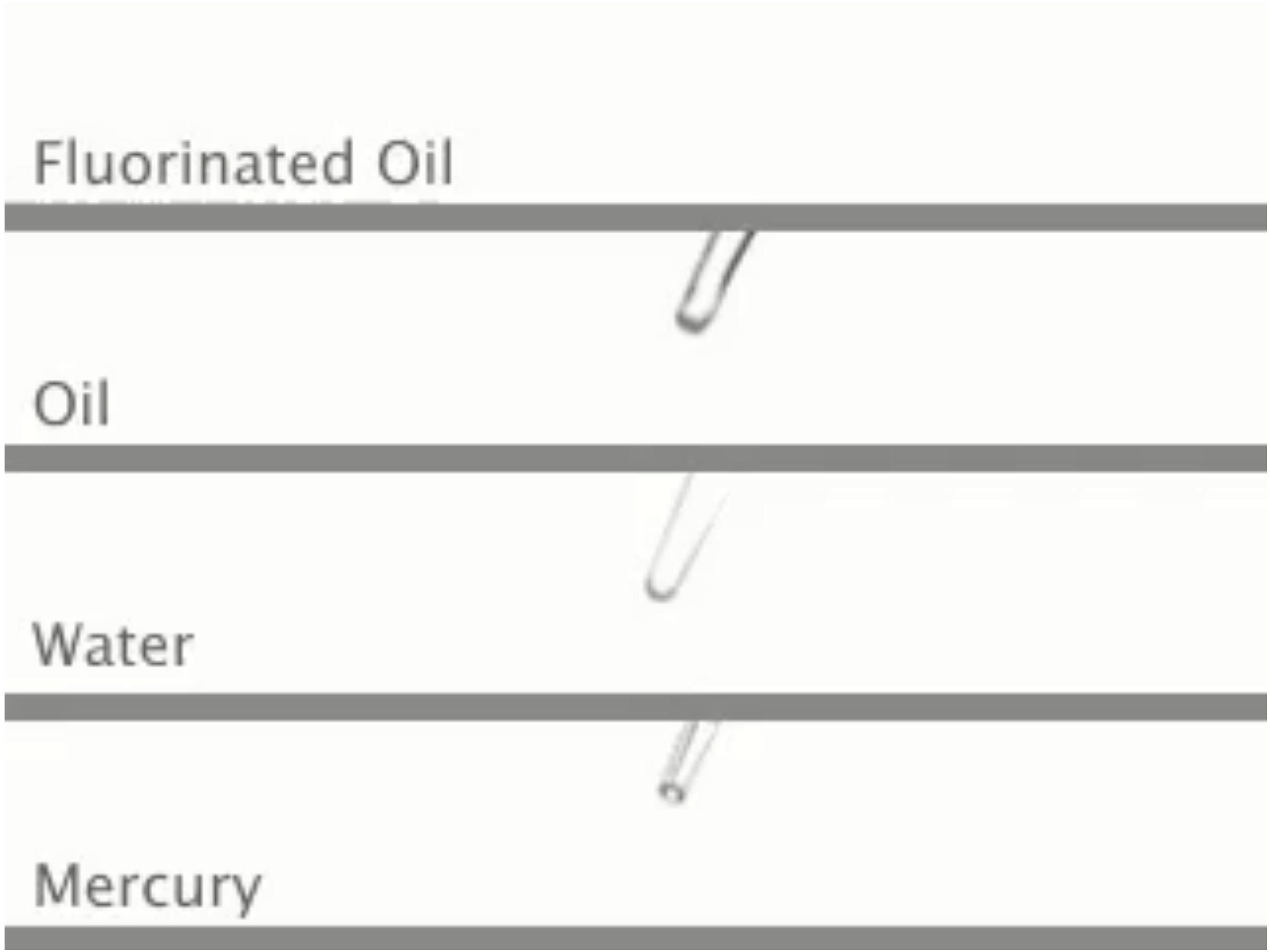
Partial wetting on a flat solid



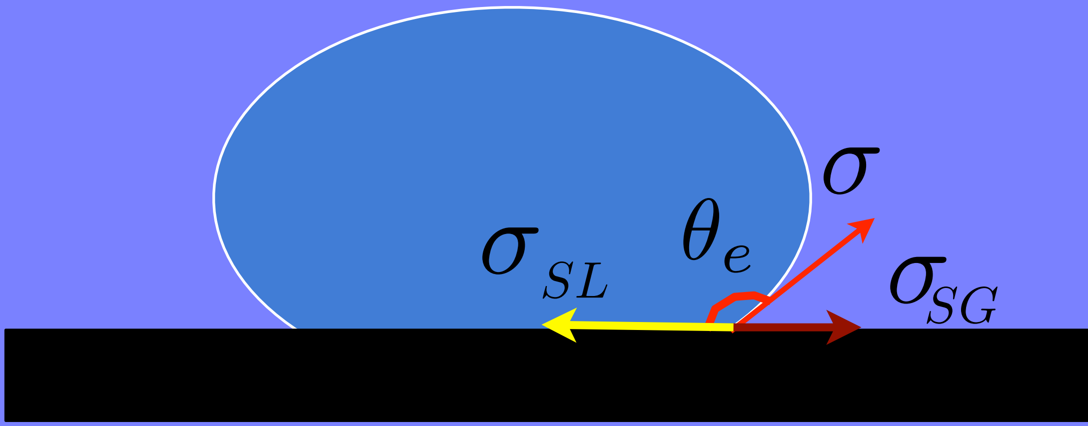
Partial wetting


2 λ


methylnaphtalene
γ = 20 mN/m
water
γ = 73 mN/m
mercury
γ = 500 mN/m


Fluorinated Oil
Oil
Water
Mercury

Fluid-Solid Contact: WETTING



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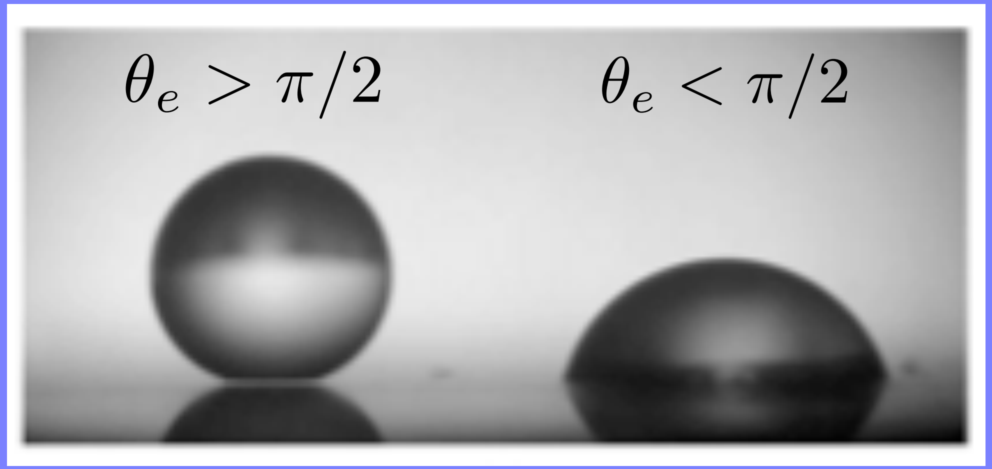
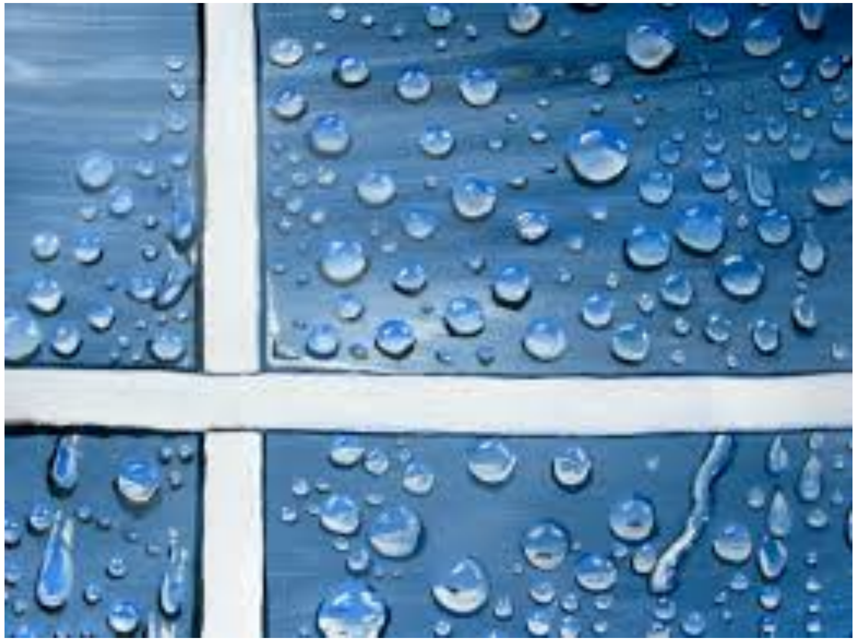


Hydrophobic surface

Hydrophilic surface

The raindrop paradox

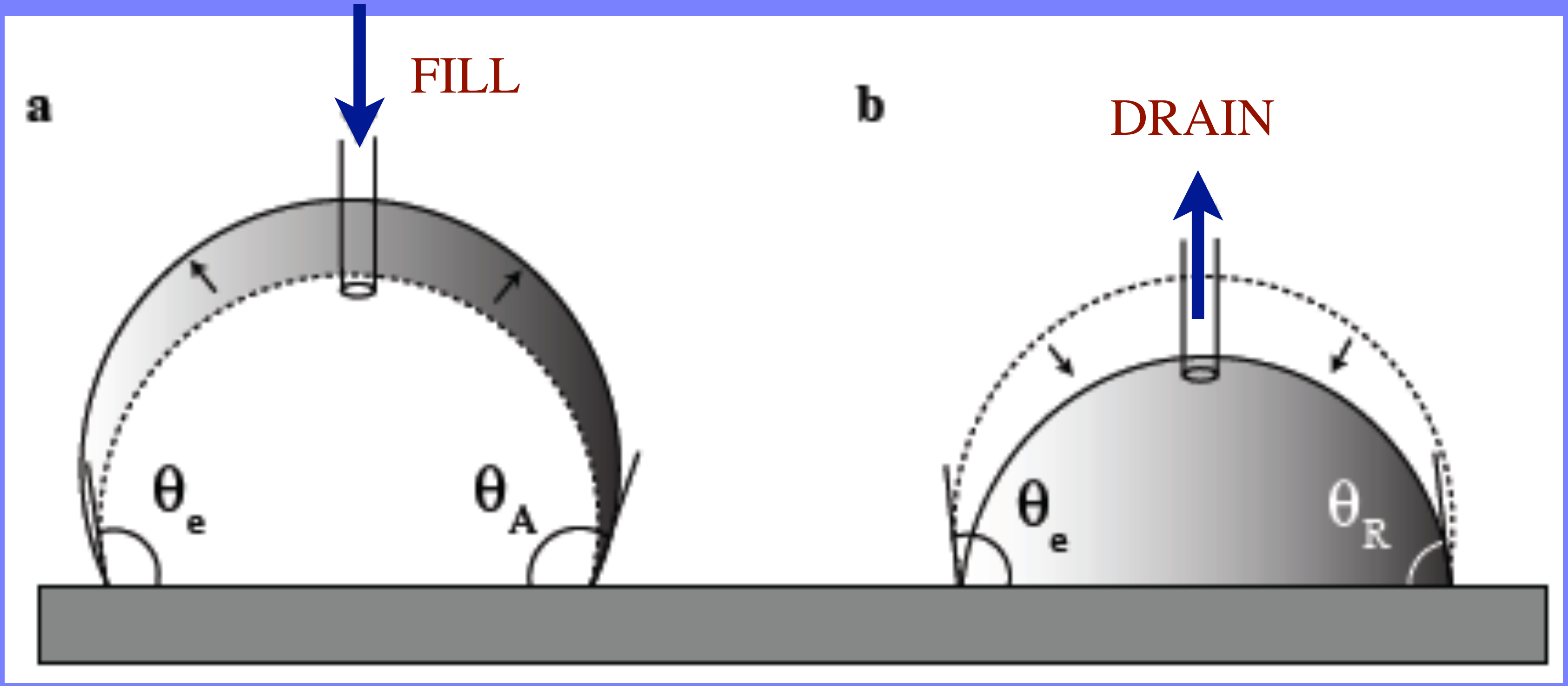


Why do drops stick?

Contact angle hysteresis

Static contact angle is not uniquely θ_e

Reality: drop is stable over a range of $\theta_r < \theta < \theta_a$



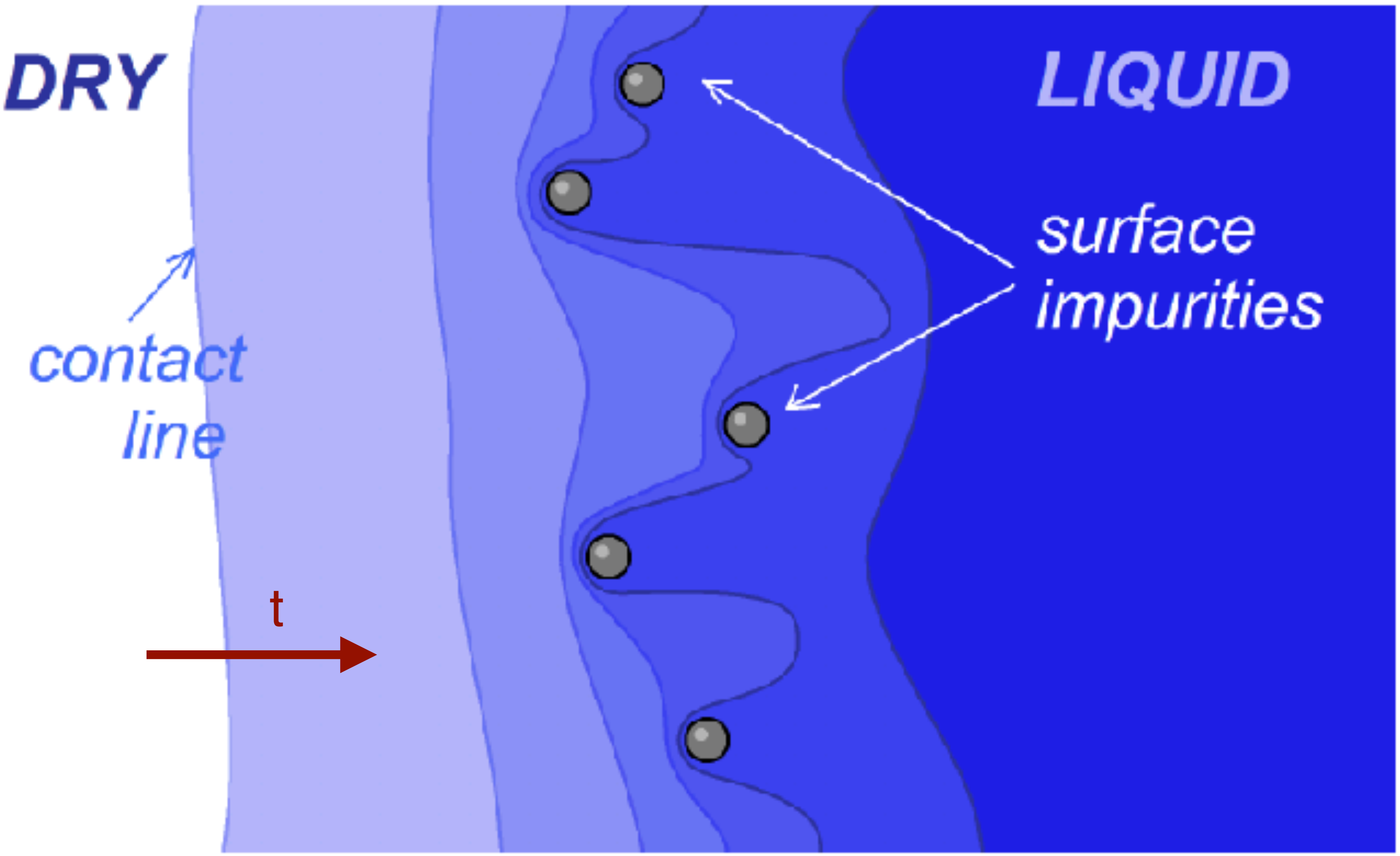
→ FORCE of ADHESION resists drop motion

increases with $\Delta\theta = \theta_a - \theta_r$

Origins: advancing contact lines pinned on surface irregularities

The origins of contact angle hysteresis

- motion of contact line past chemical/textural irregularities is energetically costly



The origins of contact angle hysteresis

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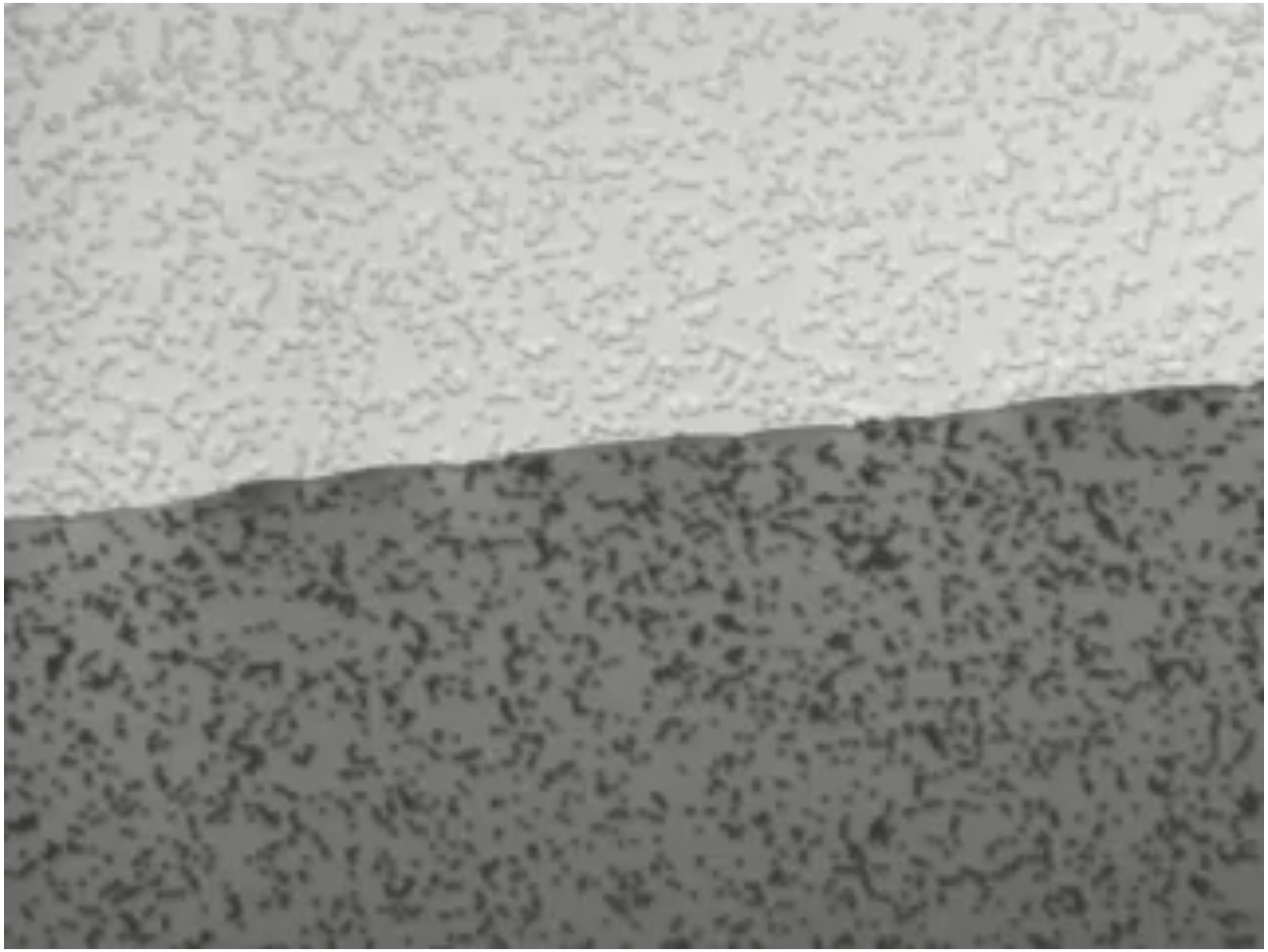
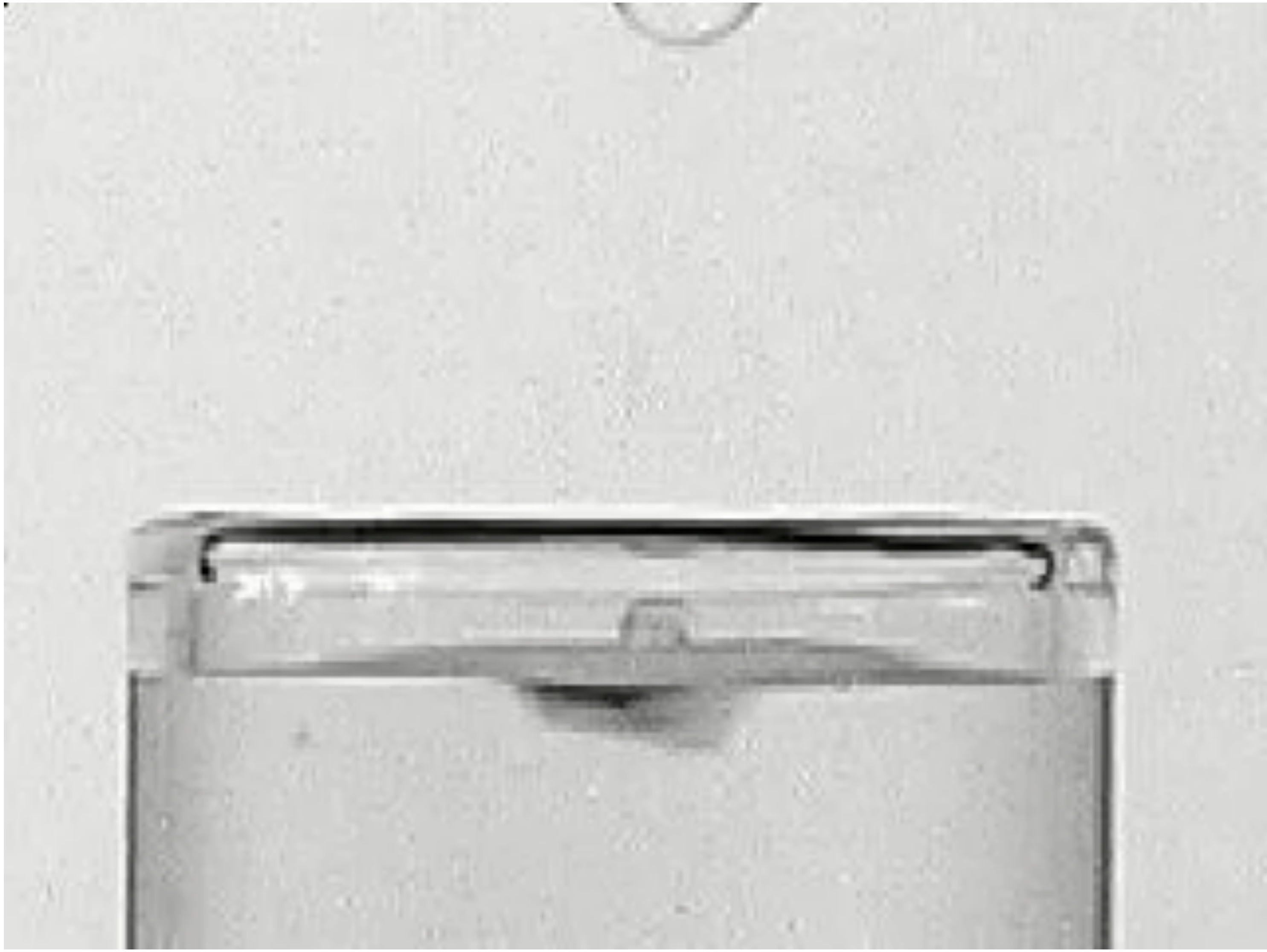
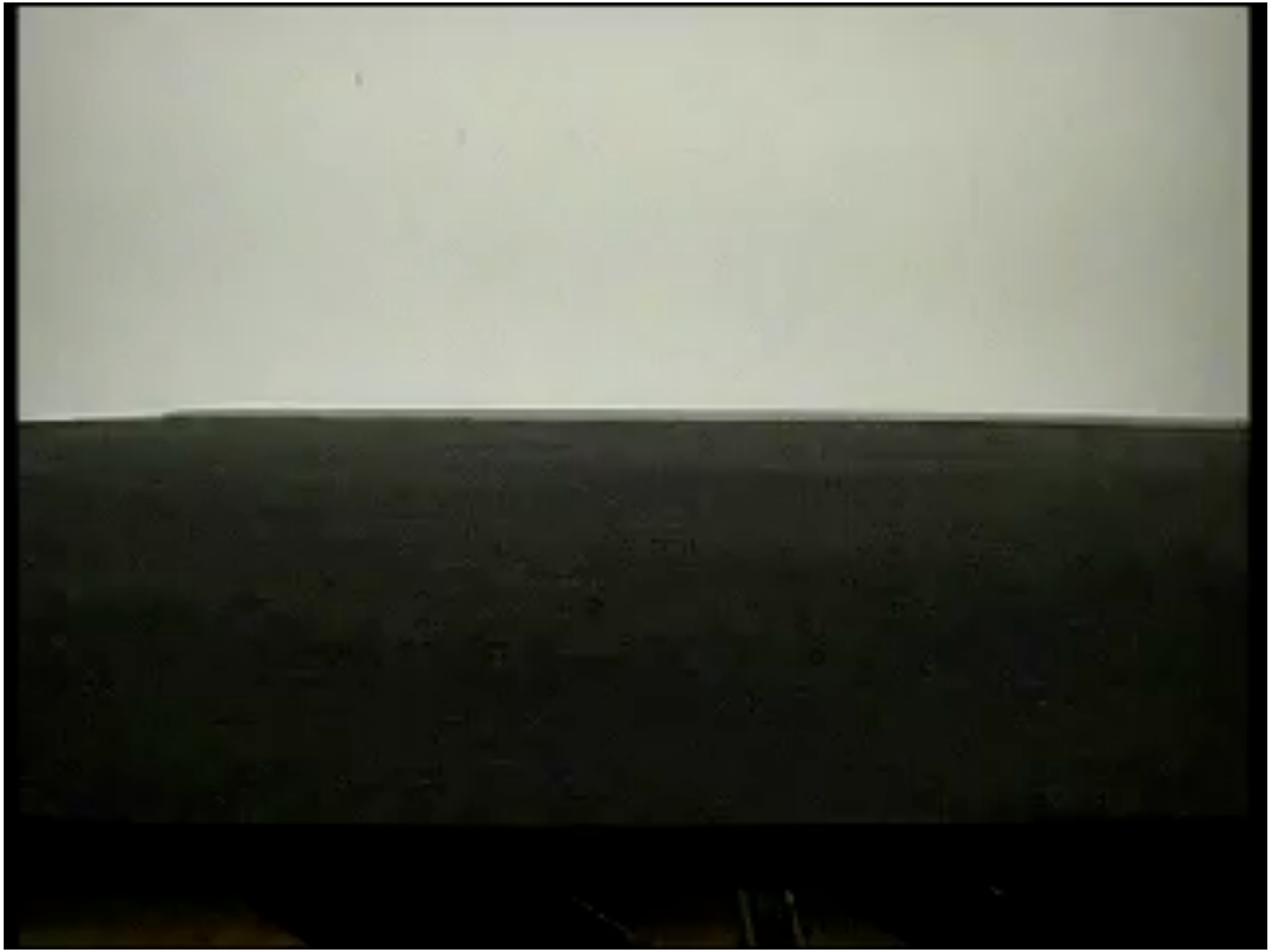


Contact angle pinning on corners



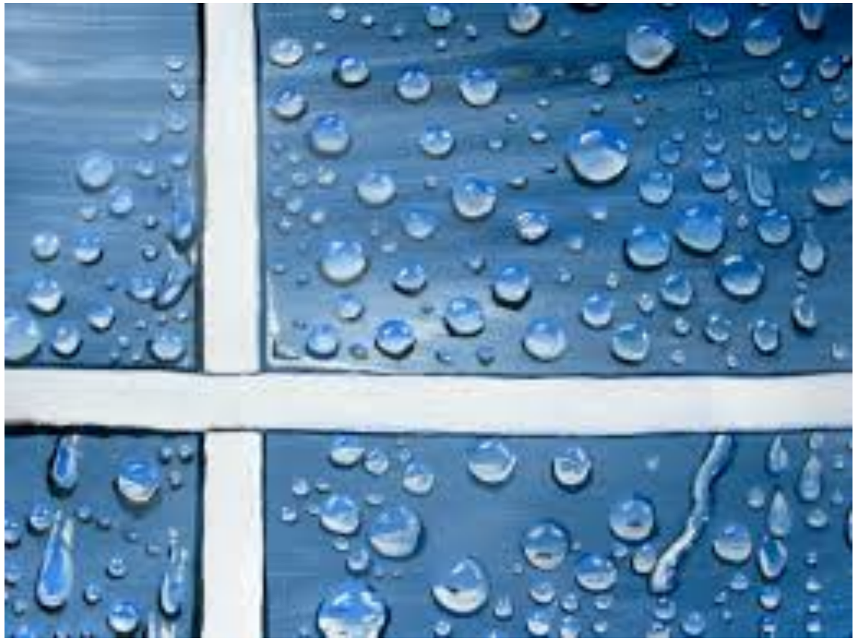
Reduce contact angle hysteresis via cleaning



Manifestations of contact angle hysteresis

- liquid slug in a capillary tube
- drops stick to solids

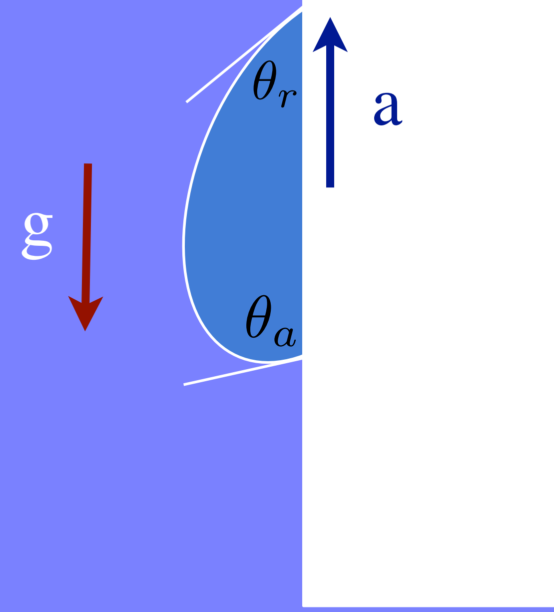
The raindrop paradox



Why do drops stick?

The force of adhesion (Dussan & Chow 1983)

Raindrop stuck on a window

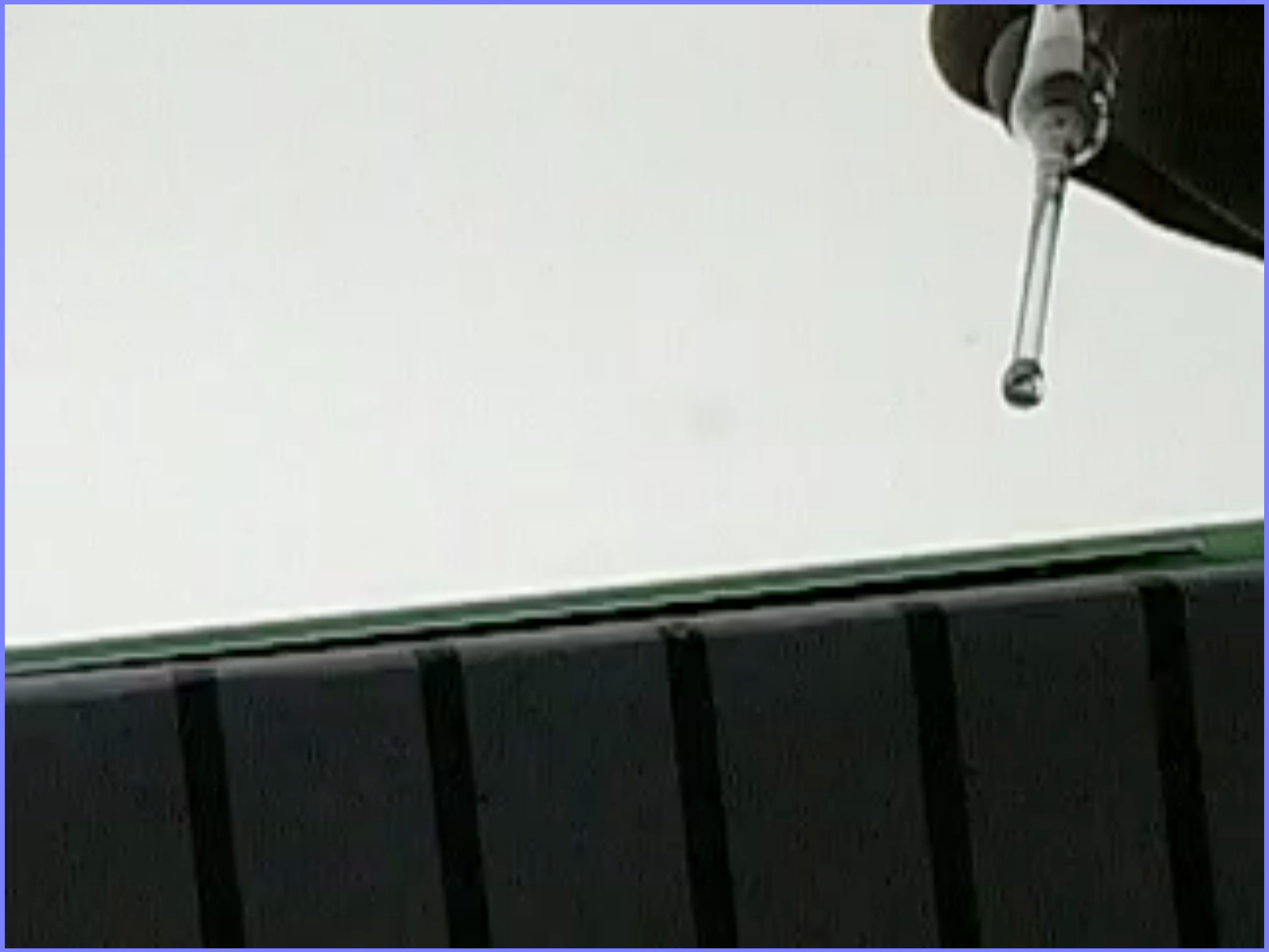


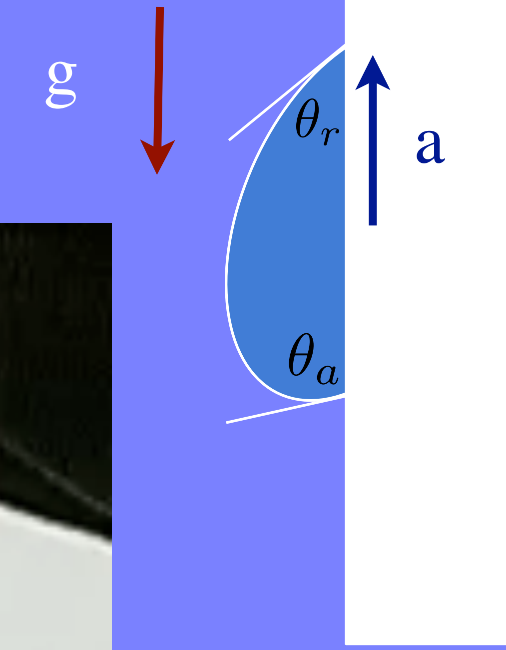
- small drops supported by contact line resistance

$$F_c \sim 2\pi a \, \sigma \, (\cos\theta_r - \cos\theta_a)$$

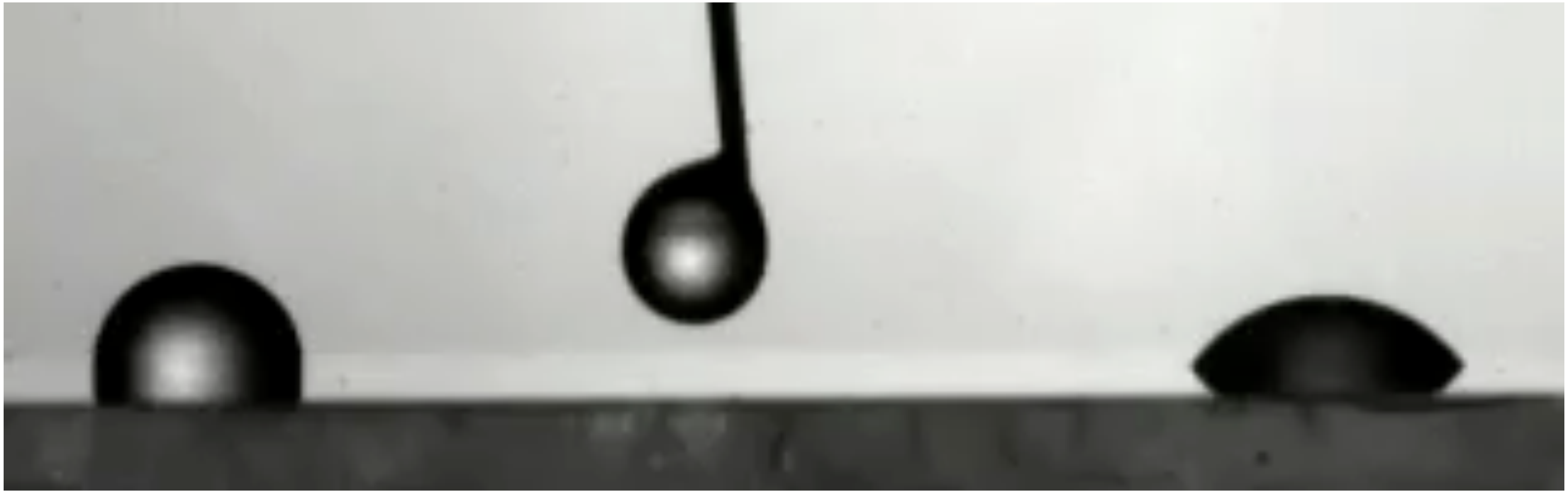
- drops grow by accretion until weight prompts rolling

The triumph of gravity over contact forces



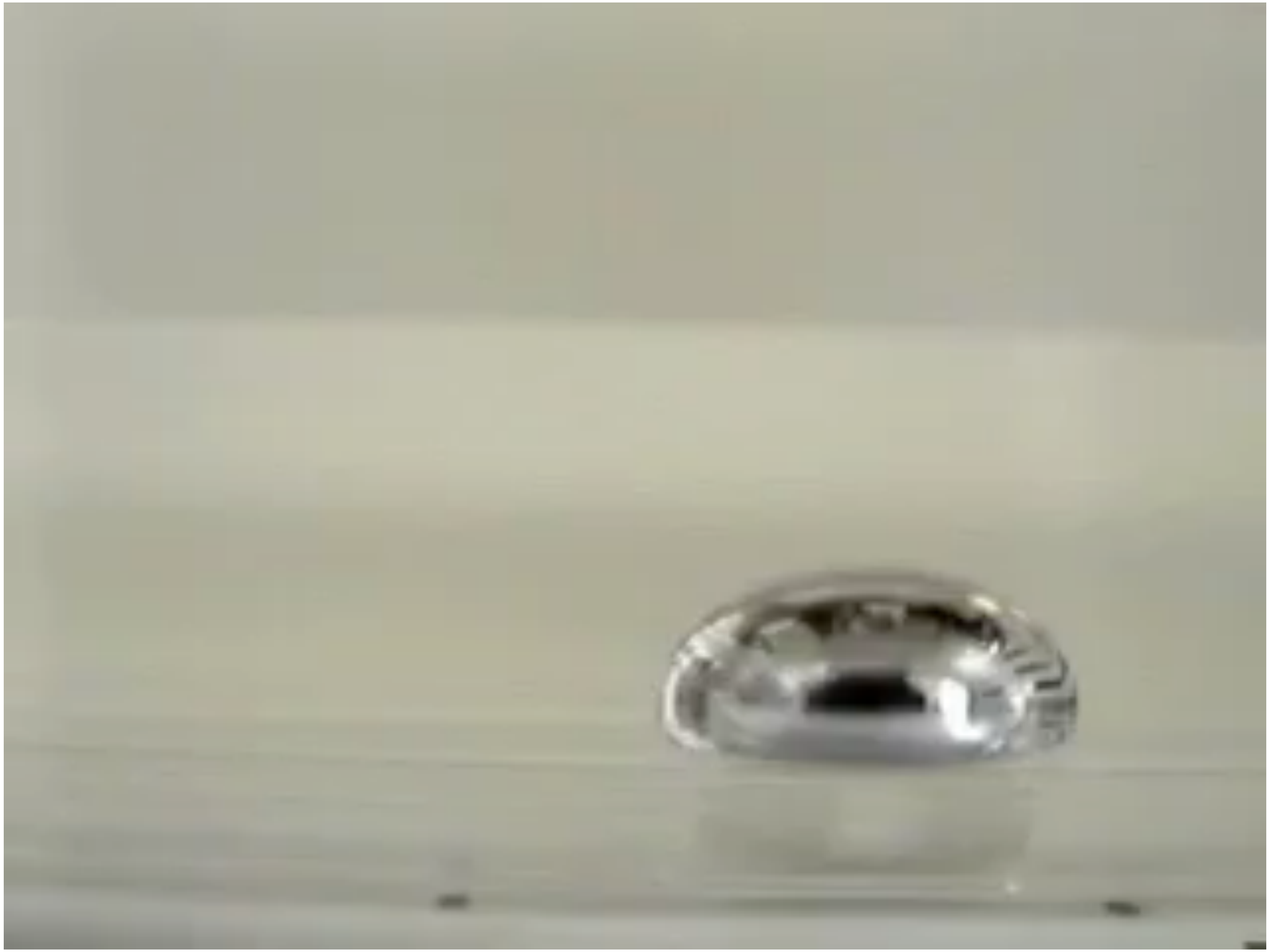


Spontaneous motion in response to a wettability gradient



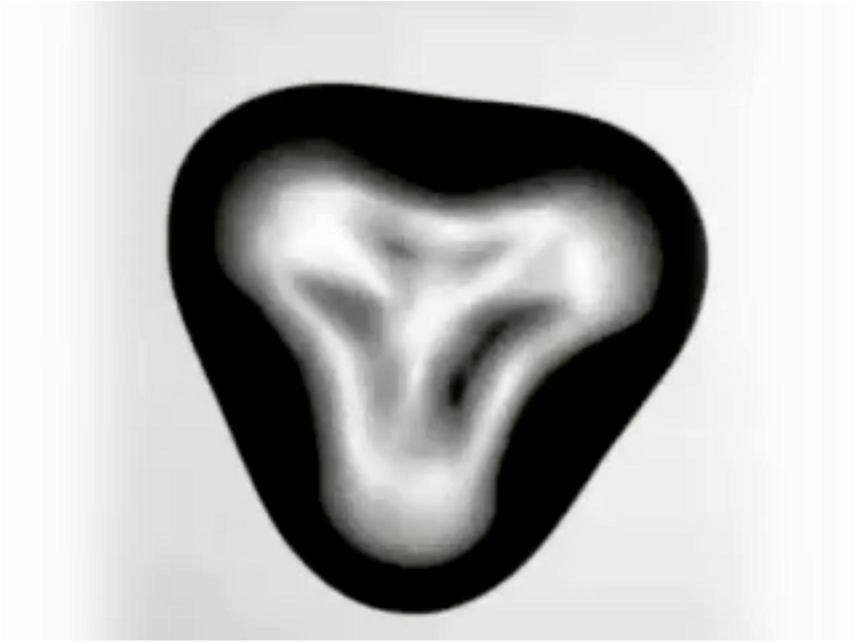
- lateral chemical force must overcome contact force

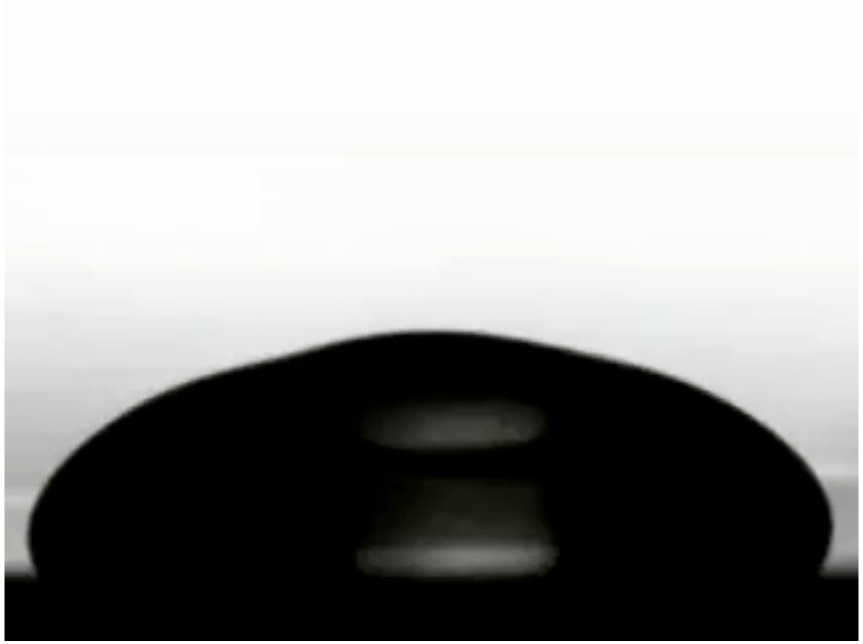
Spontaneous motion in response to a chemical gradient



- lateral chemical force must overcome contact force

Overcoming contact forces via vibration





- force at drop's natural frequency

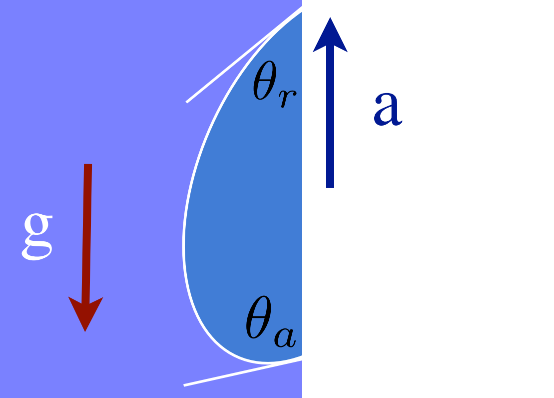
$$\rho U^2 \approx \sigma / R$$

$$\omega \sim \left(\frac{\sigma}{\rho R^3} \right)^{1/2}$$

Propulsion via contact angle hysteresis and vibration

- exploited by a class of shorebirds for feeding

The force of adhesion (Dussan & Chow 1983)



Raindrop stuck on a window

- small drops supported by contact line resistance

$$F_c \sim 2\pi a \, \sigma \, (\cos\theta_r - \cos\theta_a)$$

- drops grow by accretion until weight prompts rolling

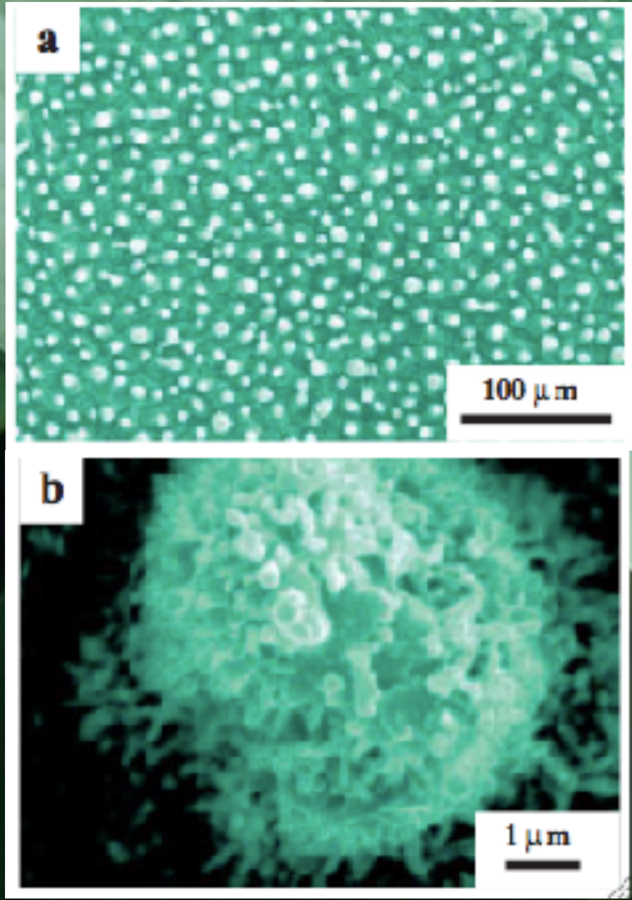
Water-repellency

- impinging drops roll off rather than adhering
- requires large θ_e , small $\Delta\theta = \theta_a - \theta_r$

How can we reduce the force of adhesion?

Water repellency in nature

"One who performs his duty without attachment, surrendering the results unto the Supreme Being, is unaffected by sinful action, as the lotus leaf is untouched by water."
Bhagavad Gita 5.10



Feng et al. (2004)

- the lotus leaf is superhydrophobic and self-cleaning by virtue of its waxy surface roughness