Wetting of hairy surfaces

Nelson R. Bernardino & Siegfried Dietrich

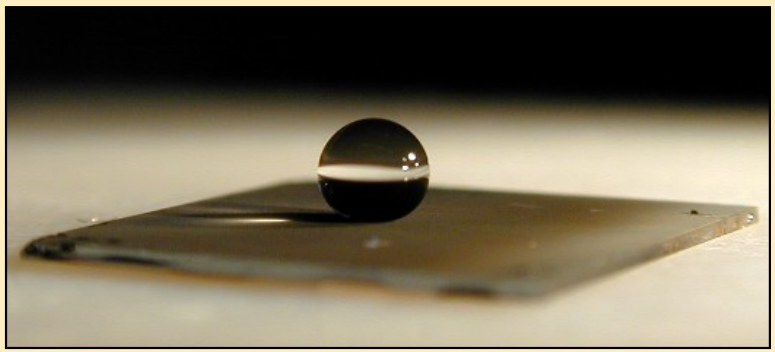
Max-Planck-Institut für Metallforschung
Stuttgart, Germany

Lisboa, 17 June 2009

Wetting and Geometry

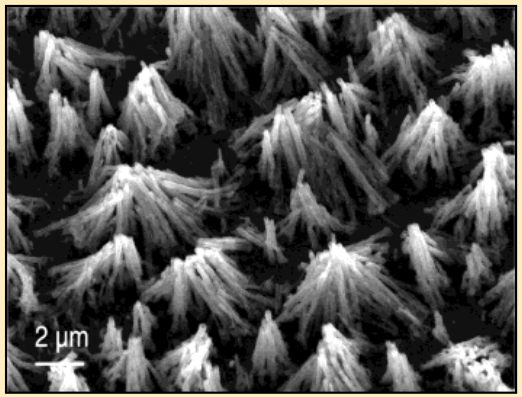
Geometry $\rightarrow$ Wetting

- Capillary condensation.
- Wedge wetting.
- Superhydrophobic surfaces.[1]



Geometry $\leftarrow$ Wetting

- Deformation of elastic surfaces.
- Colapse of patterned substrates.[1]

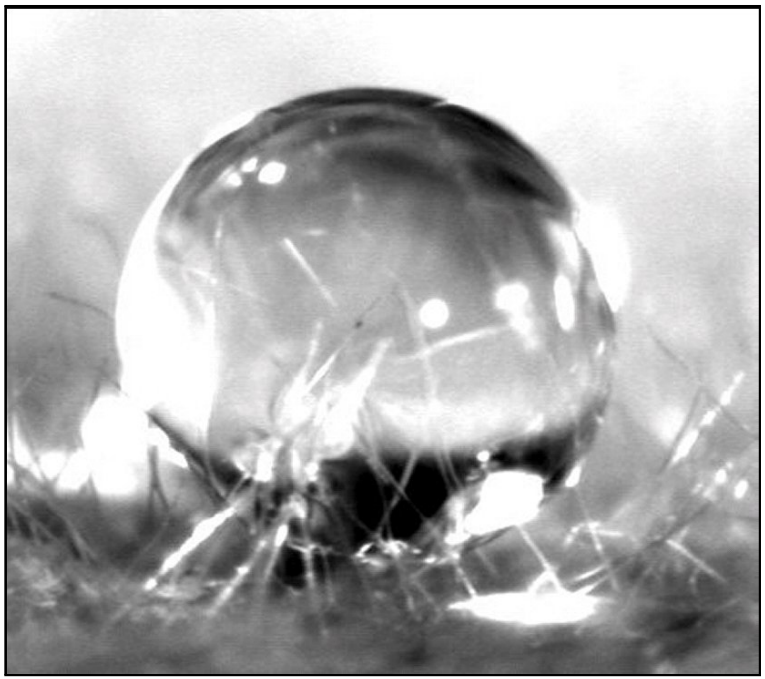


Goal: Geometry $\leftrightarrows$ Wetting.

[1] Lau et al, Nanoletters **3** (2003), 1701

An Intriguing Example: The Lady's Mantle

- Leaves covered with hydrophilic hairs.[1]
- Droplets can be suspended in the fur.



- Behaviour attributed to elasticity of the hairs.

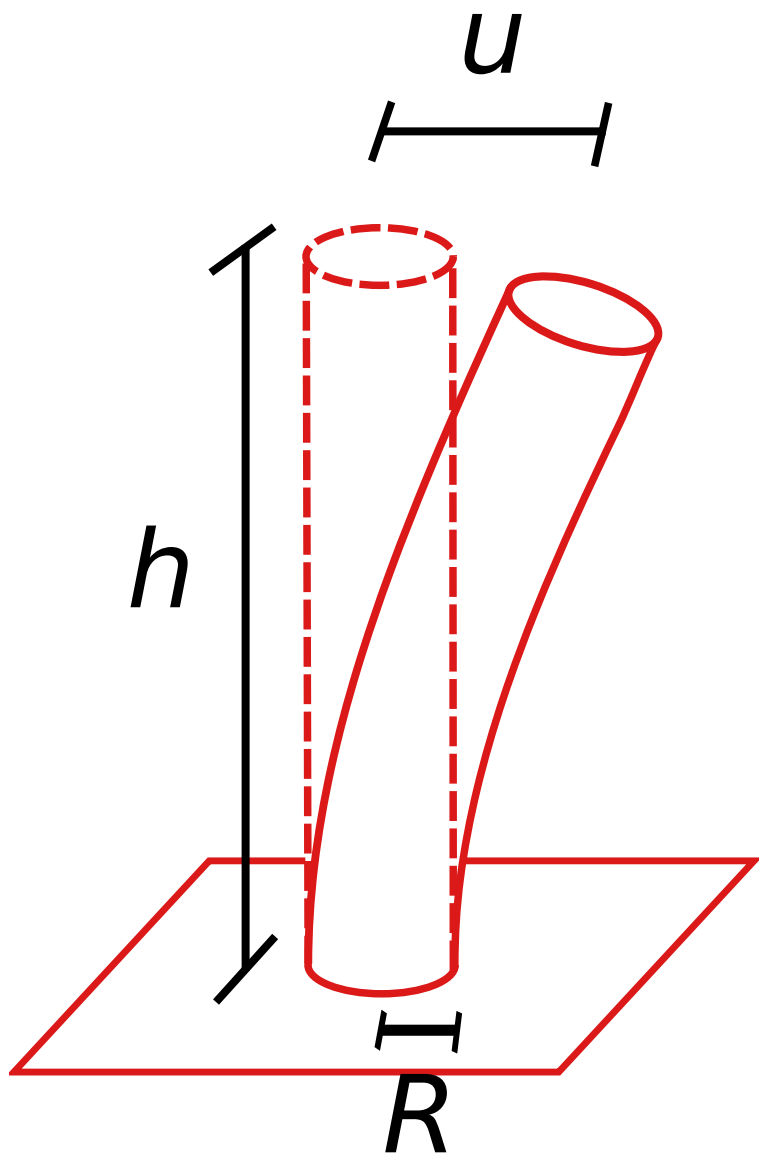
[1] Otten & Herminghaus, Langmuir **20** (2004) 2405

Simple Model I: Elastic Energy

- Elastic Energy

$$E_{\mathrm{el}} = \frac{3\pi E R^4}{8h^3} u^2$$

- $E \equiv$ Young's modulus.
- $R \equiv$ radius of posts.
- $h \equiv$ height.
- $u \equiv$ deviation from equilibrium position.

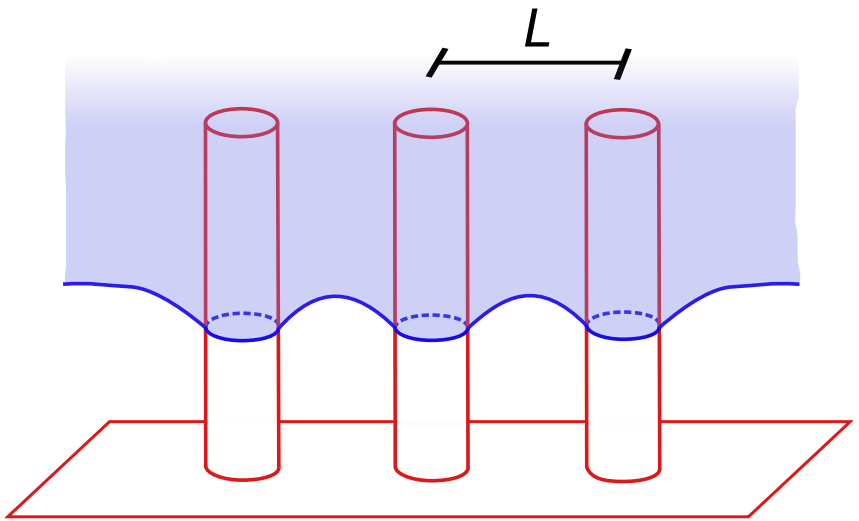


Simple Model II: Capillary Interaction

- Capillary Energy

$$E_{\text{cap}} = 2\pi\sigma R^2 \ln(qL)\cos^2\theta$$

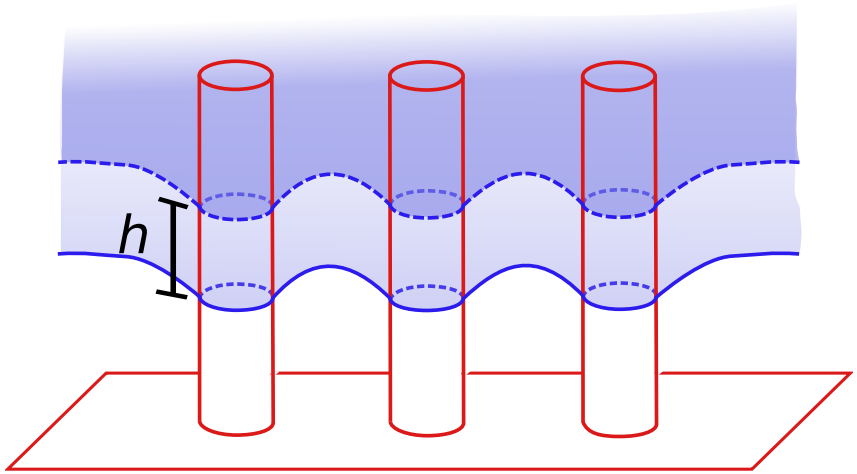
- $\sigma \equiv$ surface tension.
- $\theta \equiv$ contact angle.
- $q^{-1} \equiv$ capillary length.
- $L \equiv$ distance between centres of posts.



Simple Model III: Wetting Energy

- Wetting Energy

$$E_{\text{wet}} = 2\pi R h \sigma \cos\theta$$



Some Remarks

- Thermal fluctuations are too small.
- Non-dimensionalising we have

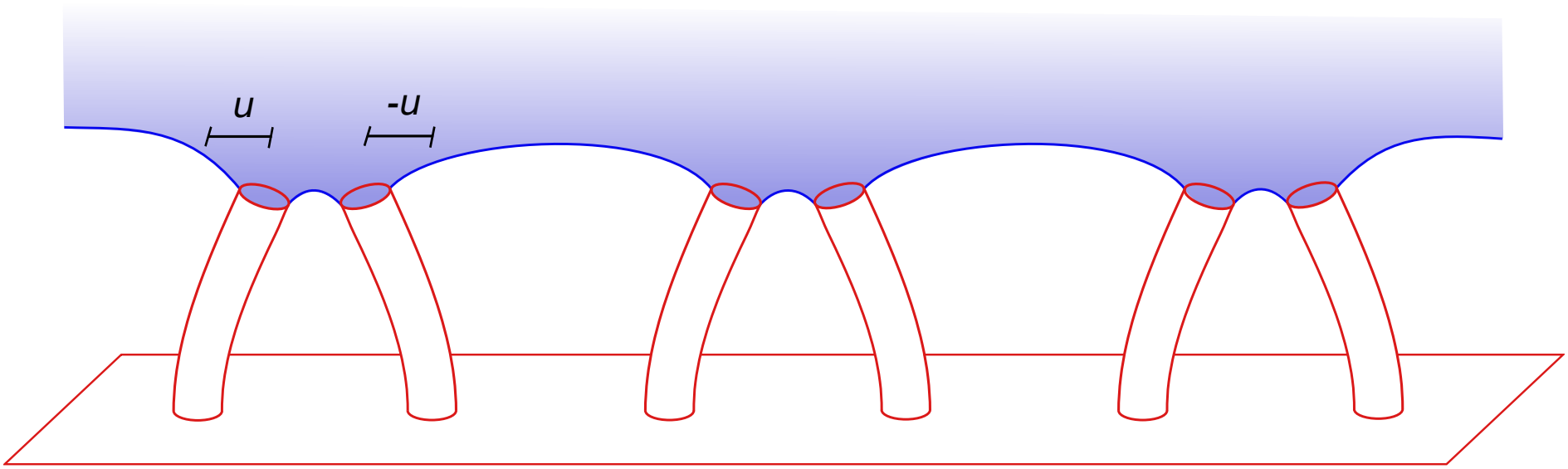
$$\overline{H} = \overline{h}\cos\theta + \frac{\overline{k}}{\overline{h}^3}\overline{u} + \ln(\overline{L})\cos^2\theta$$

- Essential parameter:

$$\overline{k} = \frac{3ER}{8\sigma}$$

- The Young's Modulus of the Lady's Mantle hairs is not known but a lower estimate is $\overline{k} \gtrsim 50$.

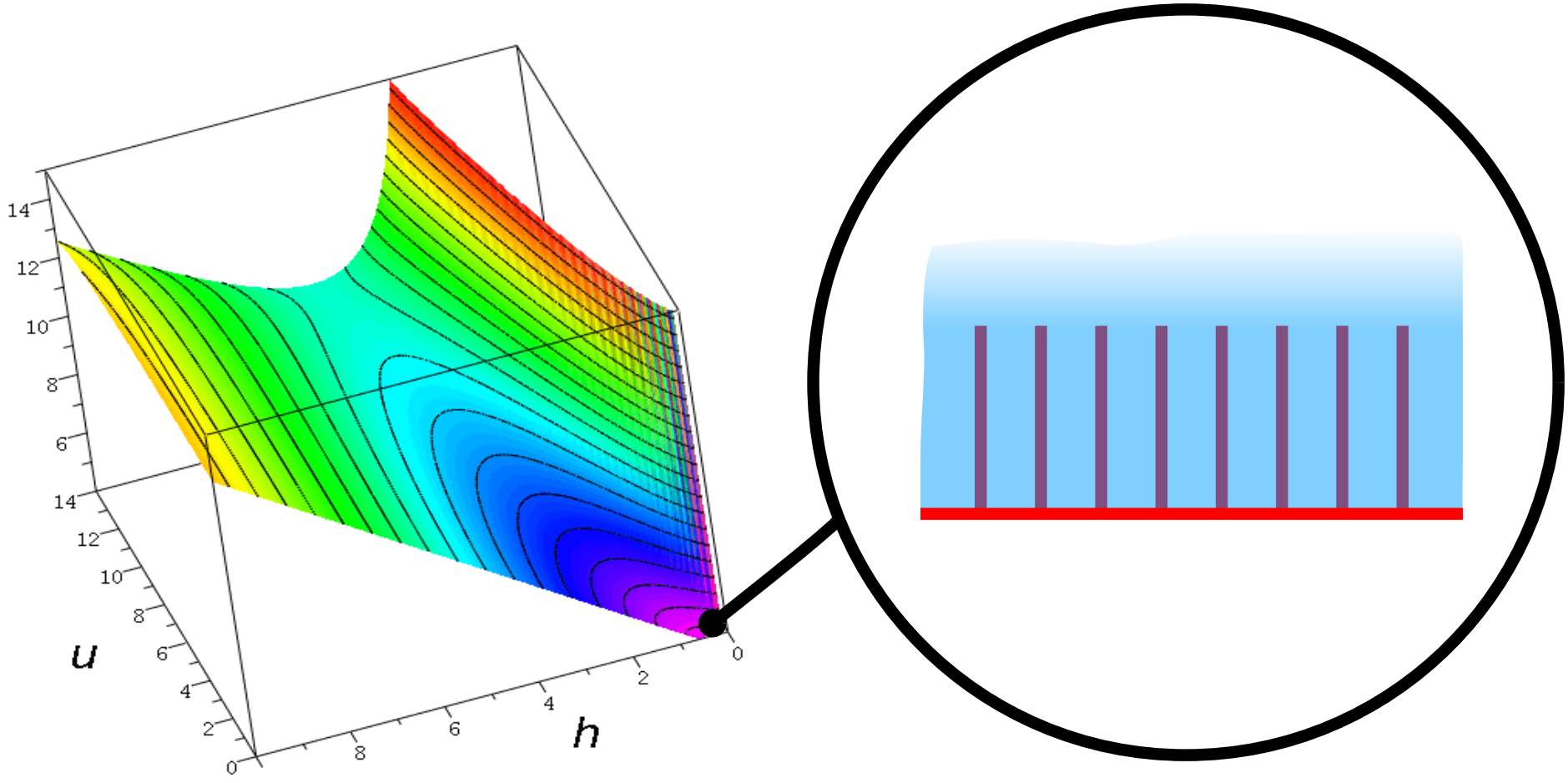
1D Toy Model I



$$H(u,h) = h\cos\theta + \frac{k}{h^3}u^2 + \frac{\ln(L-2u)\cos^2\theta}{2} + \frac{\ln(L+2u)\cos^2\theta}{2}$$

$$u \in \left[0, \frac{L-2}{2}\right]$$

1D Toy Model II



$k = 1$, $L = 30$, $\cos\theta = 1$.

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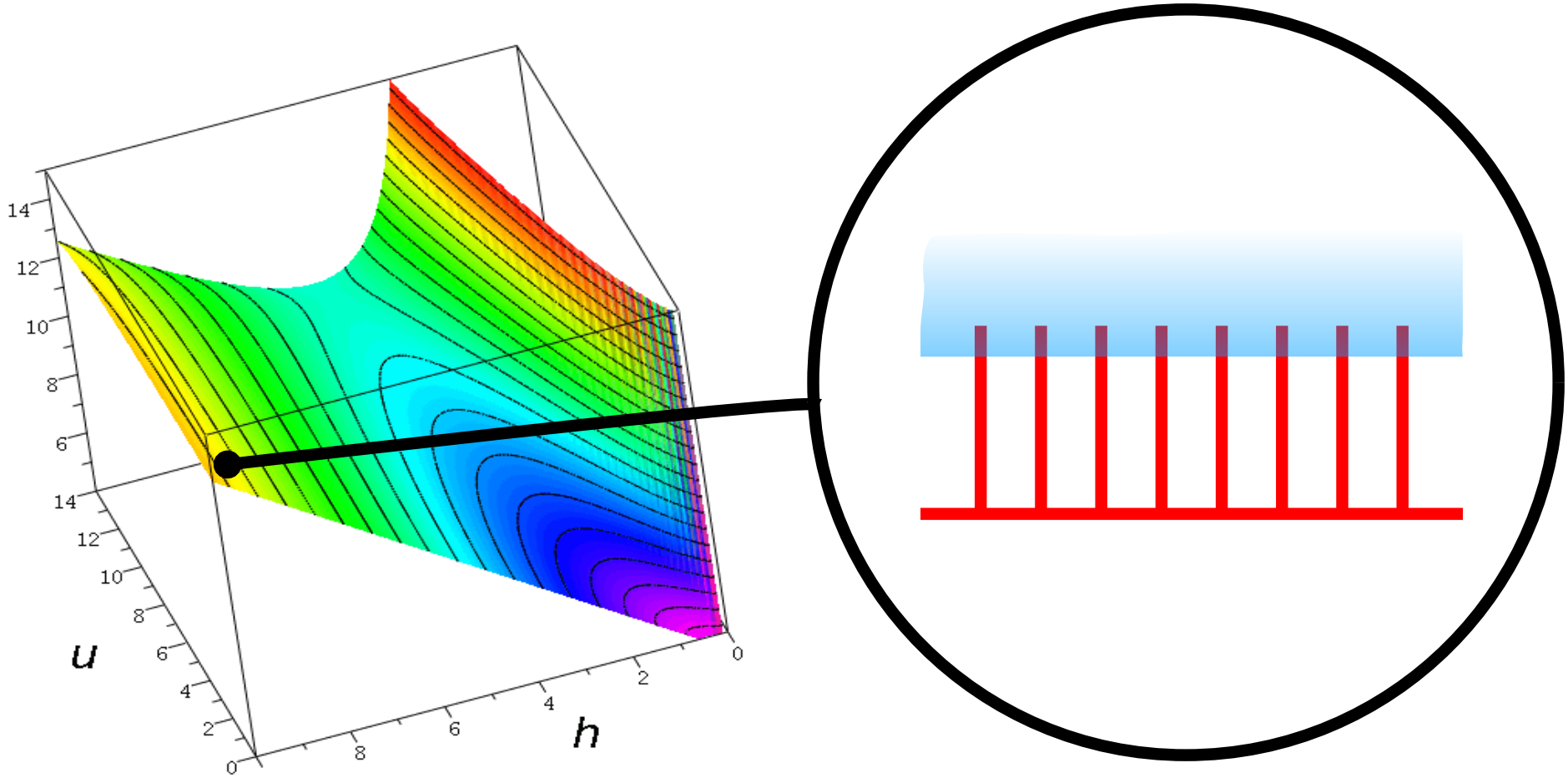

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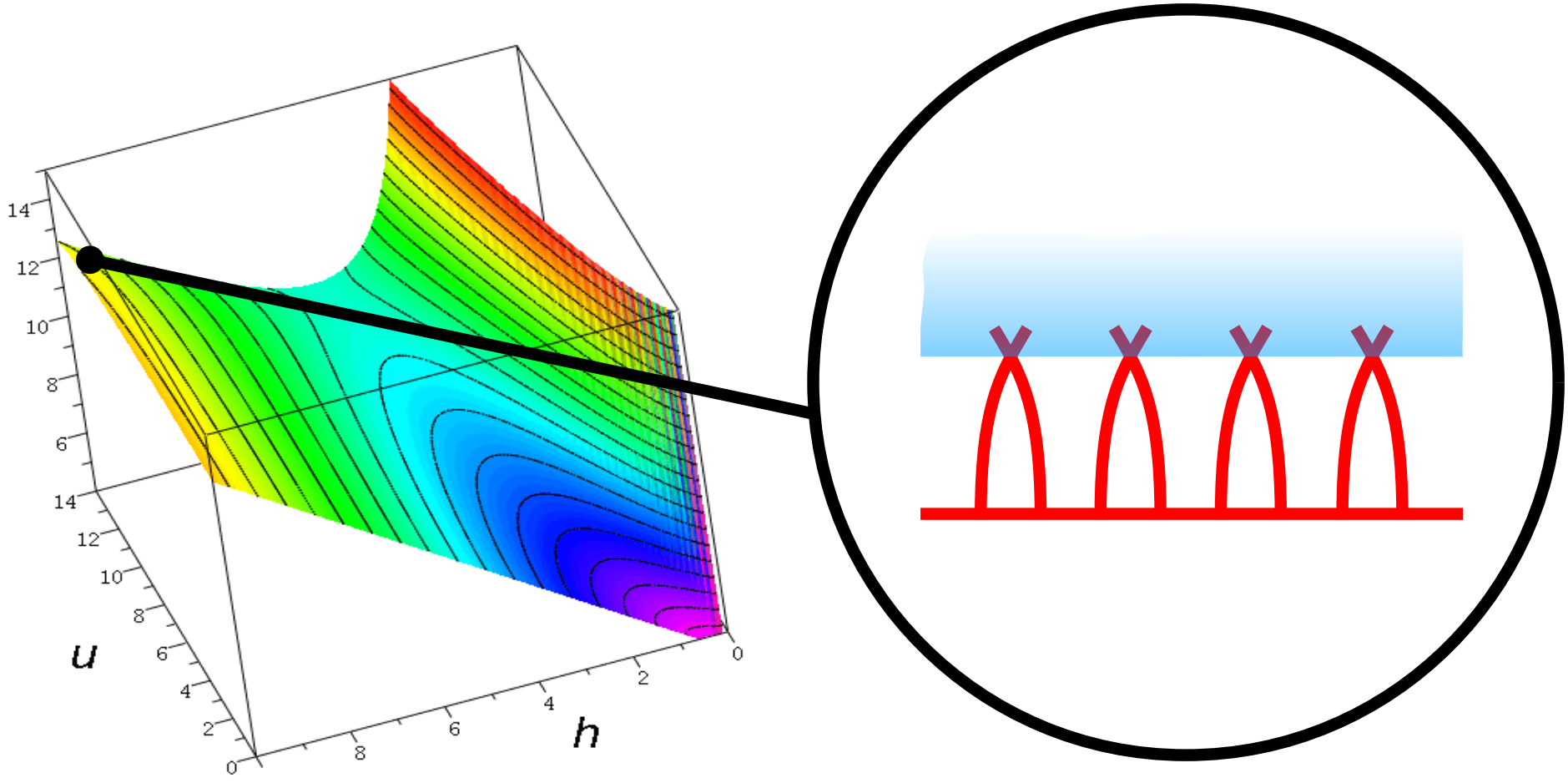

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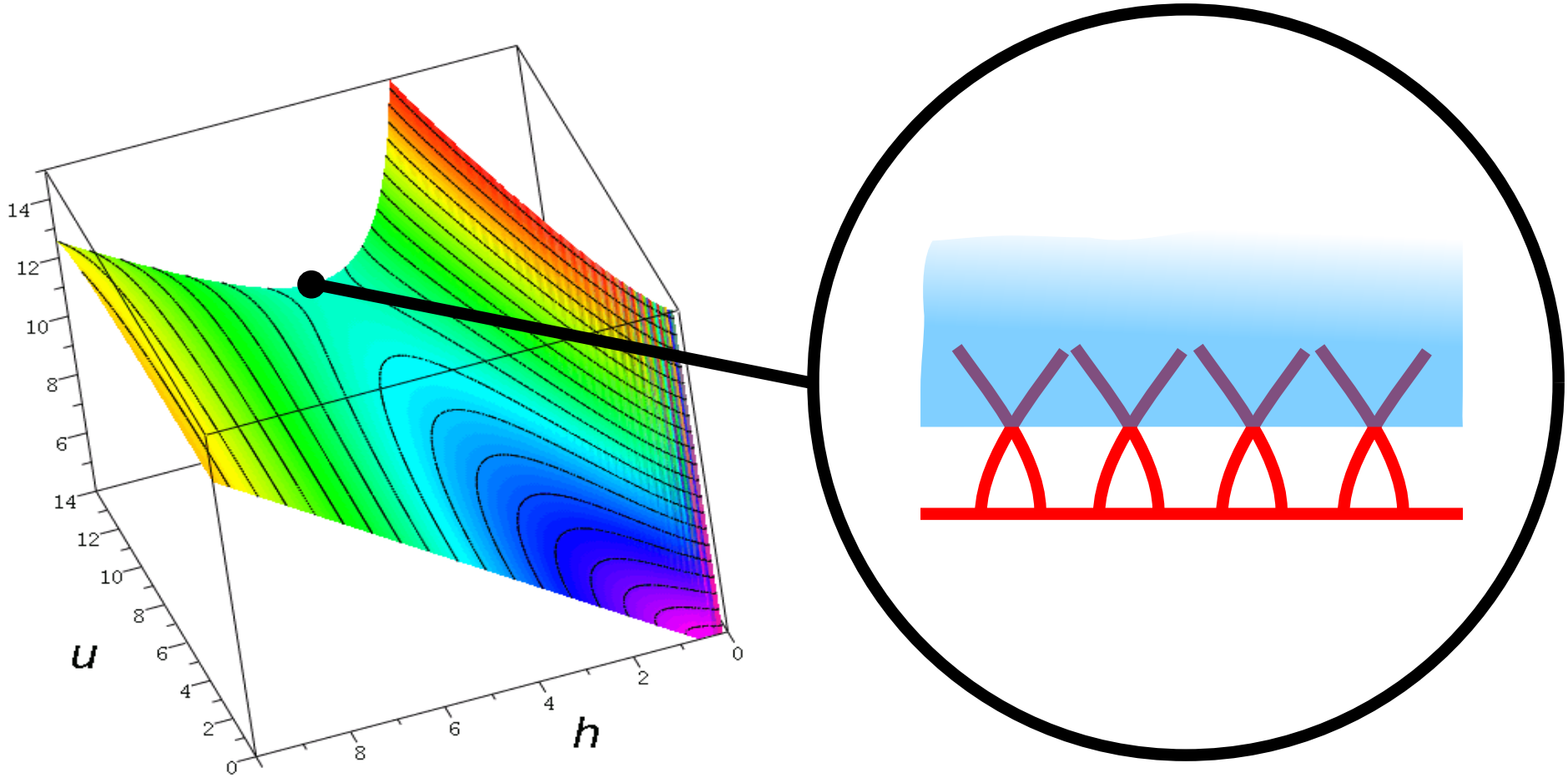

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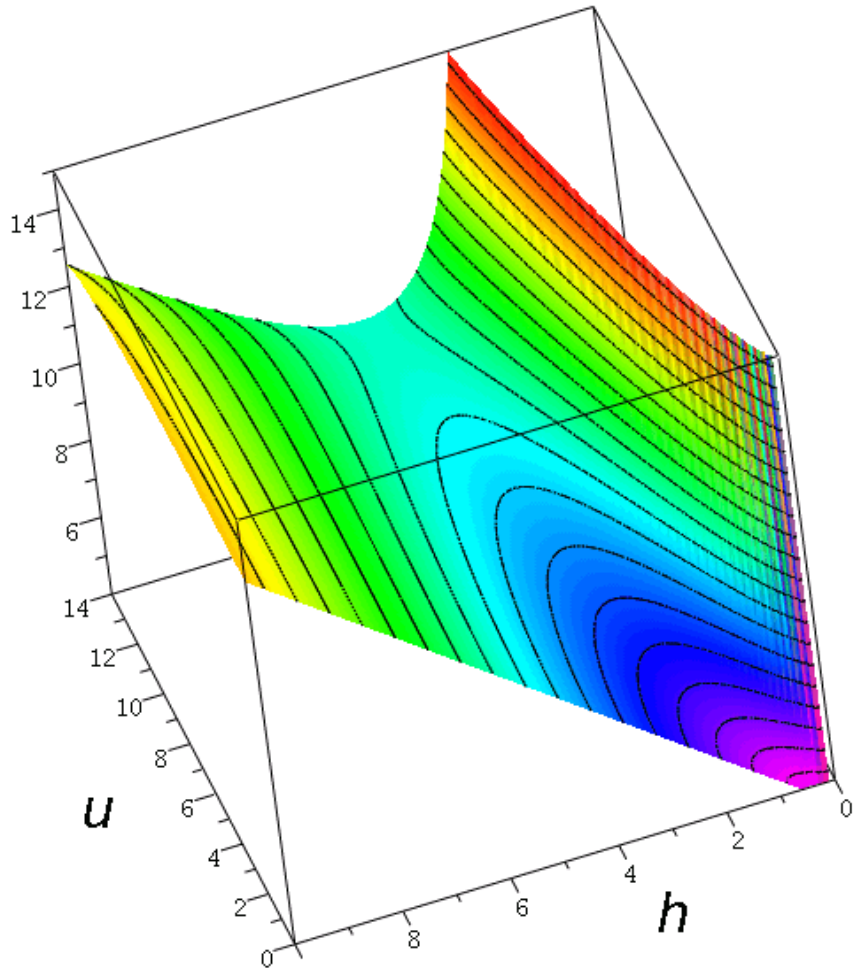

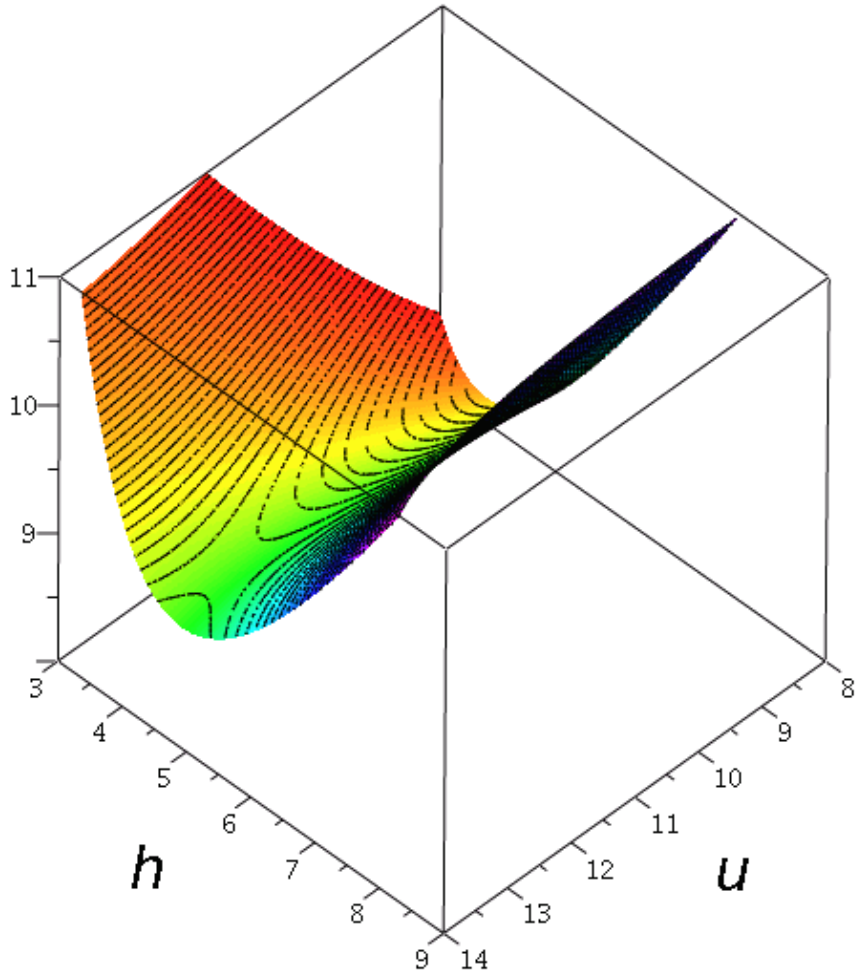

$k = 1$, $L = 30$, $\cos\theta = 1$.

Simple Estimates

- Posts bend if

$$h^3 > \frac{kL^2}{2\cos^2\theta}$$

- Elastic energy balances wetting energy when

$$h^{*4} = \frac{k(L-2)^2(n^2-1)}{4\cos\theta}$$

- Cluster holds together if

$$(L-2)^2 > 2^{10}k\frac{(n-1)^4}{(n^2-1)^3(cos\theta)^5}$$

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Simple Estimates II

- $(k = 1, \cos\theta = 1) \Rightarrow$

$$L \gtrsim 8, h^* \simeq 5.$$

- Lady's Mantle: $(k = 50, \cos\theta = 1/2) \Rightarrow$

$$L \gtrsim 250, h^* \simeq 50!$$

- With bigger clusters and pair interactions L can be smaller.
- 1D $\neq$ 2D: For Lady's Mantle

$$L \gtrsim 90, h^* \simeq 30.$$

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Thanks to Valentin Blickle (and mom)

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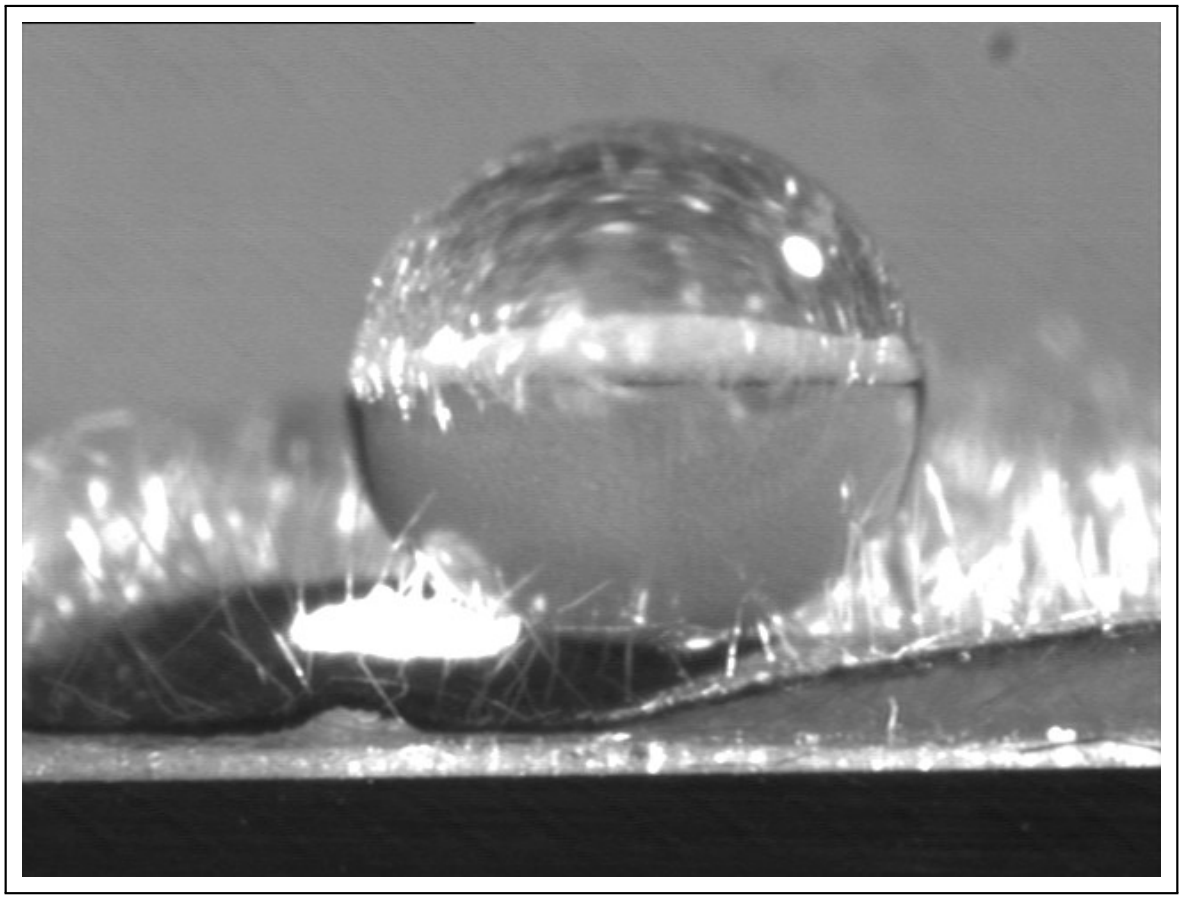

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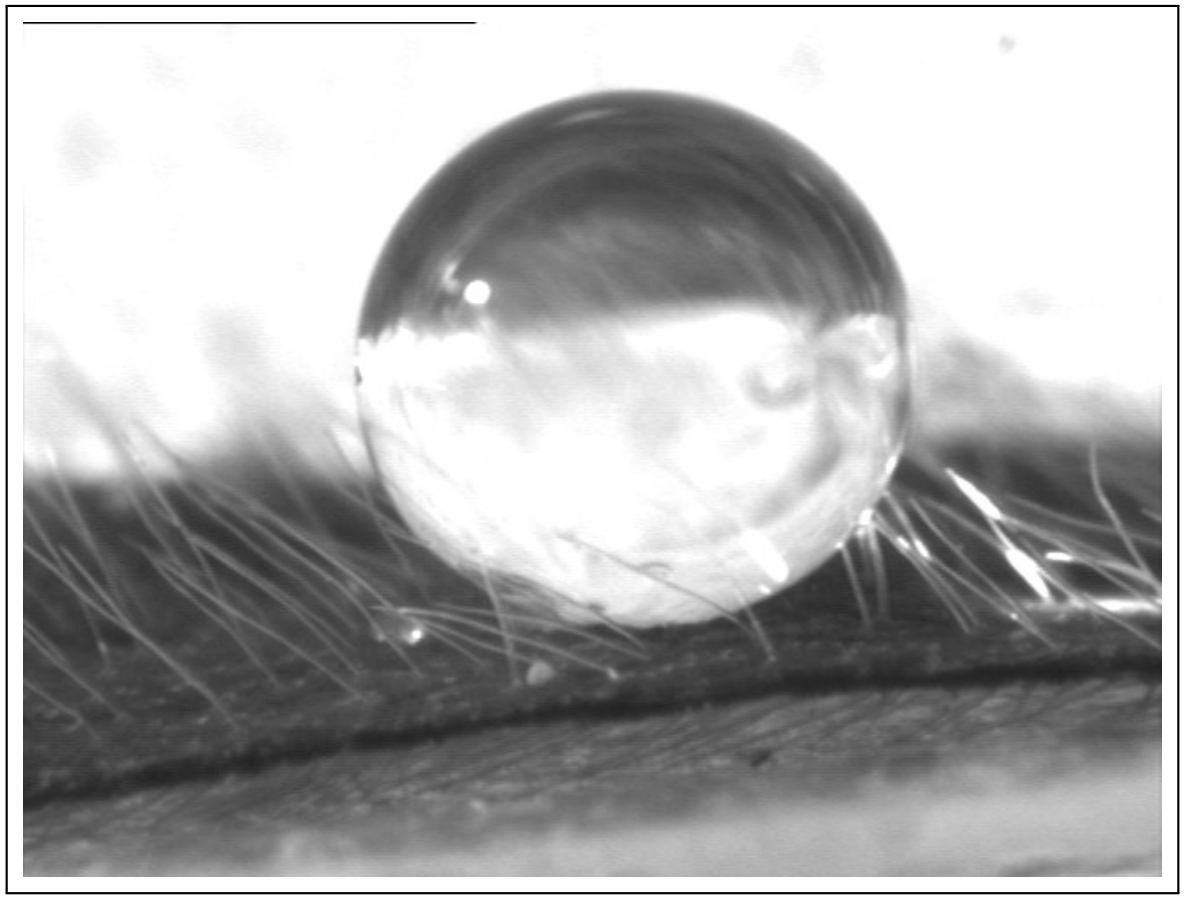

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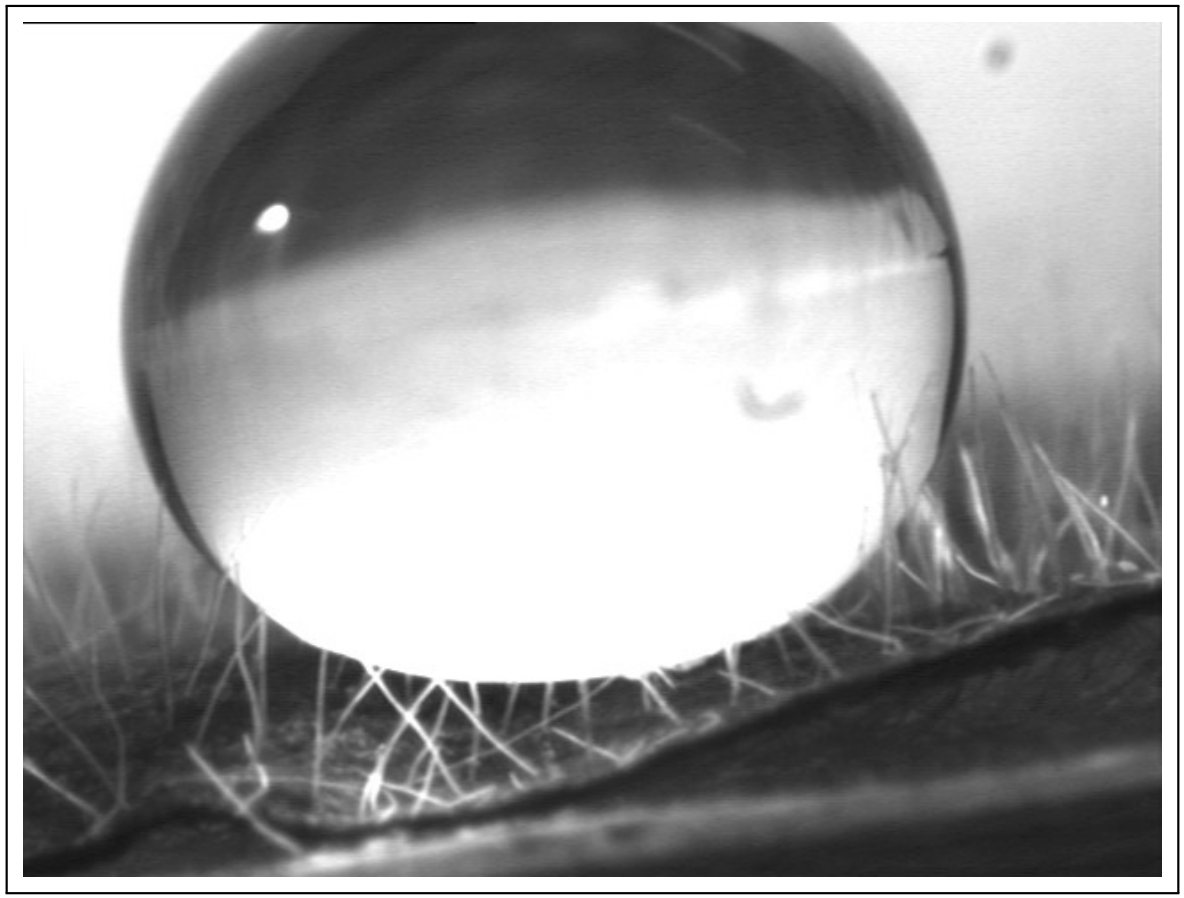

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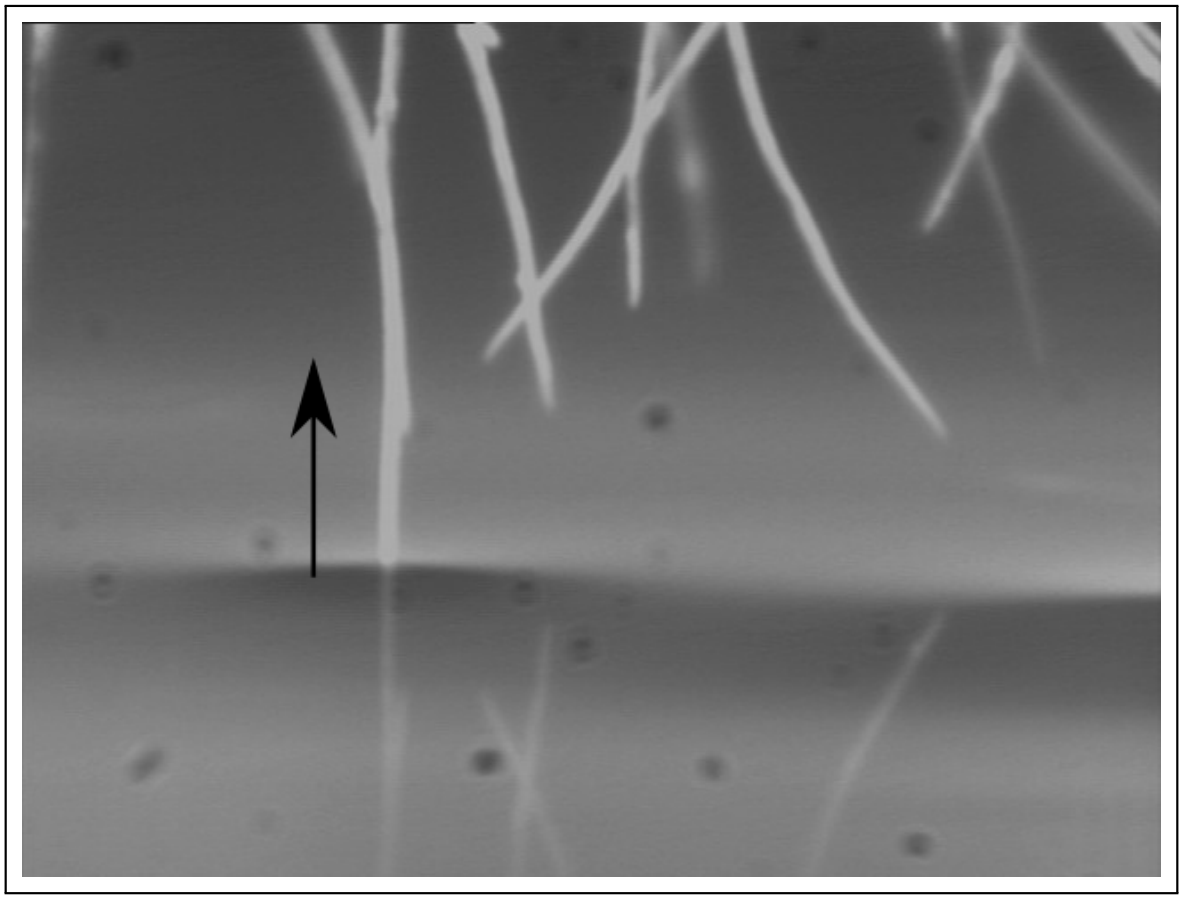

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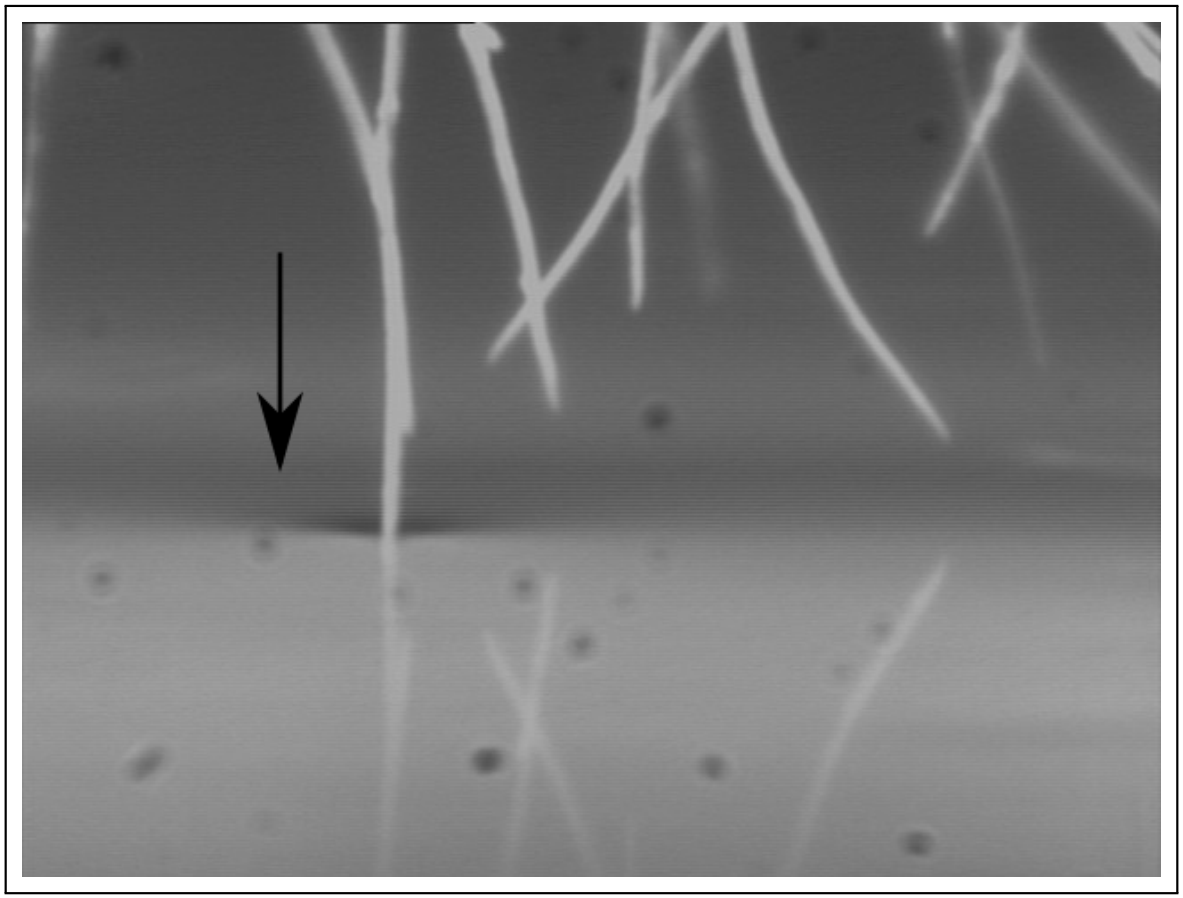

Still Missing

- Accurate estimate of energy of collapsed posts.
- Many body capillary interactions.
- Influence of lattice/disorder.
- Influence of inclined posts.
- Curvature of interface.
- Experimental verification of contact angle and hairs' Young's modulus.