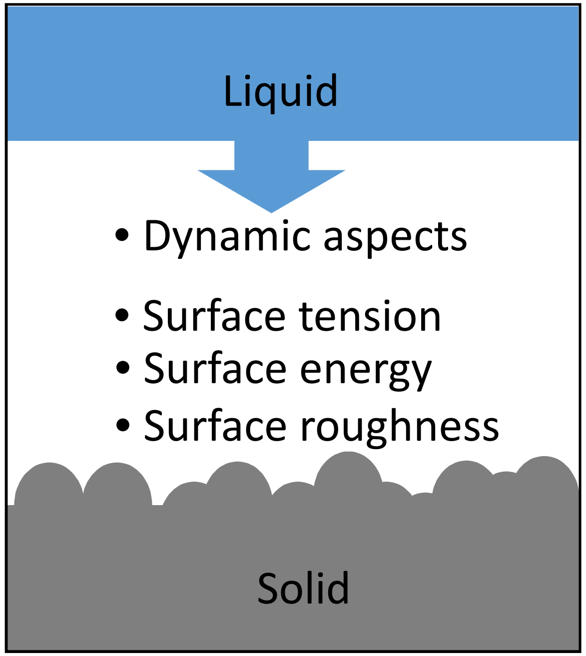
Barthlott W. and C. Neinhuis “***Purity of the sacred lotus, or escape from contamination in biological surfaces***” *(Planta (1997) 202: 1)*



Wetting/Wettability

= ability of a solid or a liquid to be wet/to maintain a contact with a liquid

Wettability

Laurent Vonna

IIS2M - Institut de Science des Matériaux de Mulhouse
Université de Haute-Alsace

1/ Surface tension and cohesive forces

2/ Wetting for a measure of the surface energy

3/ Wetting of textured surfaces

4/ Resisting wetting

5/ Liquid-infused surfaces

Gouttes, bulles, perles et ondes
Pierre Gilles de Gennes , Françoise Brochard-Wyart , David Quéré (Belin, 2002)

Journée thématique du GDR B2I, Paris, 12 octobre 2023
Techniques avancées de caractérisation de matière molle, biointerface ou biodispositif

1/ Surface tension and cohesive forces

Table 2.2 Common Types of Interactions and their Pair-Potentials $w(r)$ between Two Atoms, Ions, or Small Molecules in a Vacuum ($\varepsilon = 1$)[a]

Type of interaction		Interaction energy $w(r)$
Covalent, metallic	H_2, H_2O	Complicated, short range
Charge–charge	Q_1, r, Q_2	$+Q_1Q_2/4\pi\varepsilon_0 r$ (Coulomb energy)
Charge–dipole	Fixed dipole	$-Qu\cos\theta/4\pi\varepsilon_0 r^2$
	Freely rotating	$-Q^2u^2/6(4\pi\varepsilon_0)^2kTr^4$
Dipole–dipole	Fixed	$-u_1u_2[2\cos\theta_1\cos\theta_2 - \sin\theta_1\sin\theta_2\cos\phi]/4\pi\varepsilon_0 r^3$
	Freely rotating	$-u_1^2u_2^2/3(4\pi\varepsilon_0)^2kTr^6$ (Keesom energy)
Charge–non-polar	Q, r, α	$-Q^2\alpha/2(4\pi\varepsilon_0)^2r^4$
Dipole–non-polar	Fixed	$-u^2\alpha(1+3\cos^2\theta)/2(4\pi\varepsilon_0)^2r^6$
	Rotating	$-u^2\alpha/(4\pi\varepsilon_0)^2r^6$ (Debye energy)
Two non-polar molecules	α, r, α	$-\frac{3}{4}\frac{h\nu\alpha^2}{(4\pi\varepsilon_0)^2r^6}$ (London dispersion energy)
Hydrogen bond		Complicated, short range, energy roughly proportional to $-1/r^2$

[a] $w(r)$ is the interaction free energy or pair-potential (in J); Q, electric charge (C); u, electric dipole moment (C m); α, electric polarizibility ($C^2\,m^2\,J^{-1}$); r, distance between the centers of the interacting atoms or molecules (m); k, Boltzmann constant (1.381×10^{-23} J K^{-1}); T, absolute temperature (K); h, Planck's constant (6.626×10^{-34} J s); ν, electronic absorption (ionization) frequency (s^{-1}); ε_0, dielectric permittivity of free space ($8.854 \times 10^{-12}\,C^2\,J^{-1}\,m^{-1}$). The force $F(r)$ is obtained by differentiating the energy $w(r)$ with respect to distance r: $F = -dw/dr$. The stabilizing repulsive "Pauli Exclusion" interactions (not shown) usually follow an exponential function $w(r) \propto \exp(-r/r_0)$, but for simplicity they are usually modeled as power laws: $w(r) \propto +1/r^n$ (where $n = 9$–12).

Cohesion forces in a liquid :

- London
- Debye
- Keesom

Van der Walls Forces

- Hydrogen bonds

Intermolecular and Surface Forces, J. N. Israelachvili
Elsevier Academic Press Inc, ISBN: 978-0-12-375182-9

1/ Surface tension and cohesive forces

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	Freely rotating	$-u_1^2u_2^2/3(4\pi\varepsilon_0)^2kTr^6$ (Keesom energy)
Charge–non-polar	Q, r, α	$-Q^2\alpha/2(4\pi\varepsilon_0)^2r^4$
Dipole–non-polar	Fixed	$-u^2\alpha(1+3\cos^2\theta)/2(4\pi\varepsilon_0)^2r^6$
	Rotating	$-u^2\alpha/(4\pi\varepsilon_0)^2r^6$ (Debye energy)
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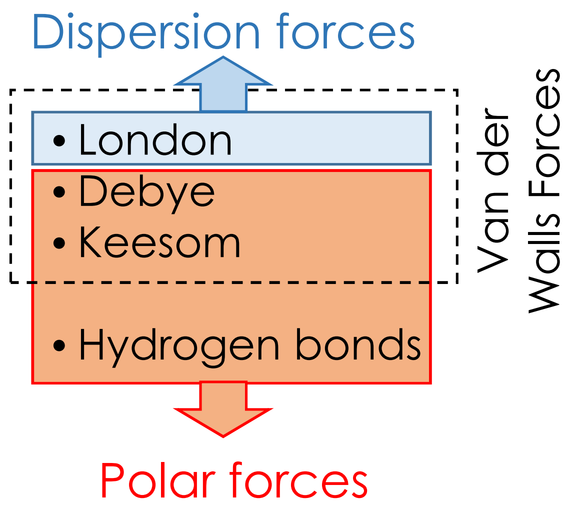
Cohesion forces in a liquid :



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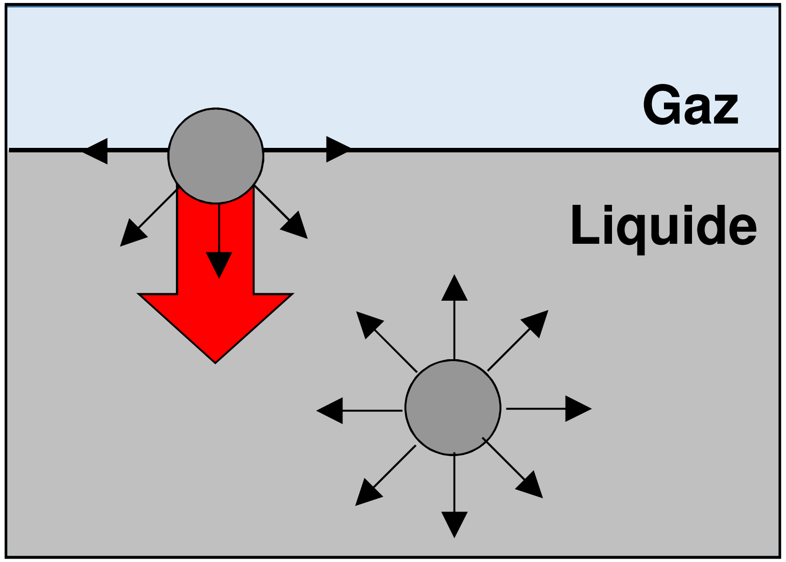
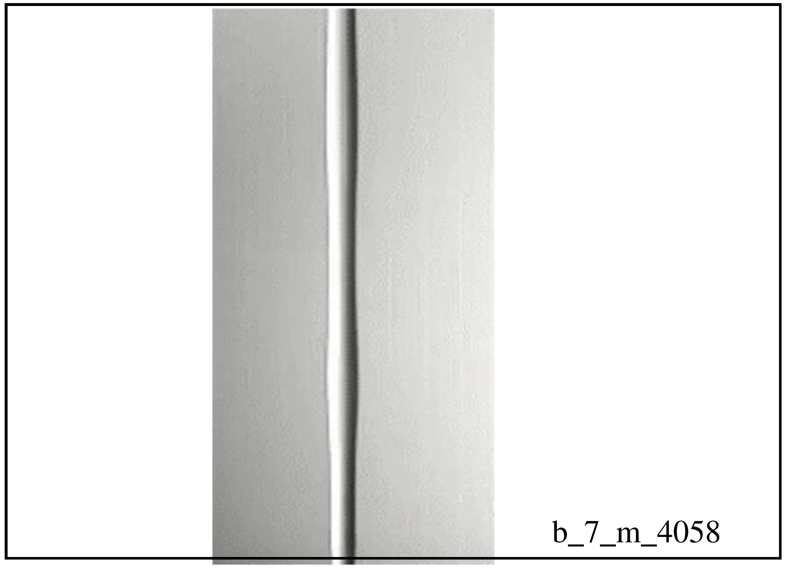
1/ Surface tension and cohesive forces



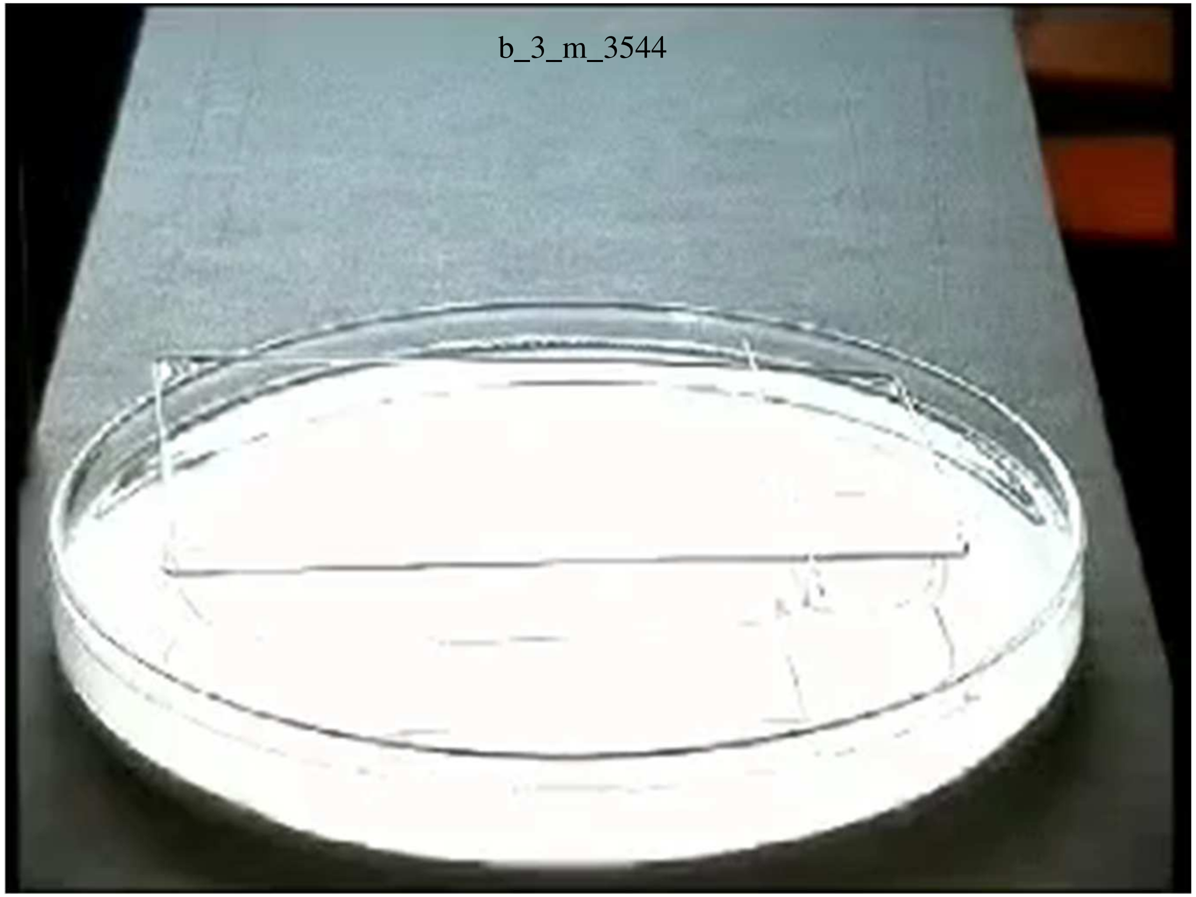


Gouttes, bulles, perles et ondes
Pierre Gilles de Gennes , Françoise Brochard-Wyart , David Quéré (Belin, 2002)

Surface energetic penalty = reduction of the interfacial area

= decrease of the ratio surface/volume

1/ Surface tension and cohesive forces



Gouttes, bulles, perles et ondes
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$$\delta W = F\,dx = 2\,\gamma l\,dx$$

with γ **the surface tension [mN.m^{-1}]**

1/ Surface tension and cohesive forces

Surface tension values

Name[1]	Mol. Formula [2]	CAS #[2]	Mol. Wt. [3]	Surface Tension[4] Total	Dispersion	Polar	Acid	Base
Trichloromethane (chloroform)	$CHCl_3$	67-66-3	119.38	27.2	27.2	0.0	1.5	0.0
Diiodomethane (methylene iodide)	CH_2I_2	75-11-6	267.84	50.8	50.8	0.0	0.01	0.0
Diiodomethane (methylene iodide)	CH_2I_2	75-11-6	267.84	50.8 (5)	49.0[5]	1.8 (5)	0.01	0.0
Diiodomethane (methylene iodide)	CH_2I_2	75-11-6	267.84	50.8 (6)	44.1[6]	6.7 (6)	0.01	0.0
Diiodomethane (methylene iodide)	CH_2I_2	75-11-6	267.84	50.8 (12)	48.5[12]	2.3 (12)	0.01	0.0
Formamide (methanamide)	CH_3NO	75-12-7	45.04	58	39	19	2.28	39.6
Formamide (methanamide)	CH_3NO	75-12-7	45.04	58.2 (5)	36.0[5]	22.2 (5)	2.28	39.6
Formamide (methanamide)	CH_3NO	75-12-7	45.04	57.9 (7)	34.3[7]	23.5 (7)	2.28	39.6
Formamide (methanamide)	CH_3NO	75-12-7	45.04	58.2 (12)	39.5[12]	18.7 (12)	2.28	39.6
Methanol (methyl alcohol)	CH_4O	67-56-1	32.04	22.5	18.2	4.3	0.06 (10)	77 (10)
Ethanol (ethyl alcohol)	C_2H_6O	64-17-5	46.07	21.4	18.8	2.6	0.02 (10)	68 (10)

https://www.accudynetest.com

Dimethyl sulfoxide (DMSO)	C_2H_6OS	67-68-5	78.13	44	36	8	0.5	32
Ethylene glycol	$C_2H_6O_2$	107-21-1	62.07	48	29	19	3.0	30.1
Ethylene glycol	$C_2H_6O_2$	107-21-1	62.07	48.8 (7)	32.8[7]	16.0 (7)	3.0	30.1
Glycerol	$C_3H_8O_3$	56-81-5	92.09	64	34	30	3.92	57.4
Glycerol	$C_3H_8O_3$	56-81-5	92.09	63.4 (5)	40.6[5]	22.8 (5)	3.92	57.4
Glycerol	$C_3H_8O_3$	56-81-5	92.09	63.4 (7)	37.0[7]	26.4 (7)	3.92	57.4
2-Butanone (methyl ethyl ketone)	C_4H_8(							
Tetrahydrofuran	C_4H_8(							
Ethyl acetate (ethyl ethanoate)	C_4H_8C							
Diethyl ether (ethoxyethane)	C_4H_{10}							
2-Ethoxyethanol (ethylene glycol monoethyl ether)	C_4H_{10}(							
Benzene	C_6H_6							

Cyclohexane	C_6H_{12}	110-82-7	84.16	25.2	25.2	0.0	0.0	0.0
Toluene	C_7H_8	108-88-3	92.13	28.5	28.5	0.0	0.0	0.72
n-Heptane	C_7H_{16}	142-82-5	100.20	20.1	20.1	0.0	0.0	0.0
o-Xylene	C_8H_{10}	95-47-6	106.17	30.1	30.1	0.0	0.0	0.58
1-Bromonaphthalene	$C_{10}H_7Br$	90-11-9	207.07	44.4	44.4	0.0	-	-
cis-Decahydronaphthalene (*cis*-decalin)	$C_{10}H_{18}$	493-01-6	138.25	32.2	32.2	0.0	0.0	0.0
Decane	$C_{10}H_{22}$	124-18-5	142.28	23.8	23.8	0.0	-	-
Hexadecane	$C_{16}H_{34}$	544-76-3	226.44	27.5	27.5	0.0	0.0	0.0
Tricresyl phosphate	$C_{21}H_{21}O_4P$	1330-78-5 (9)	368.36	40.9 (5)	39.8[5]	1.1 (5)	-	-
Tricresyl phosphate	$C_{21}H_{21}O_4P$	1330-78-5 (9)	368.36	40.9 (8)	39.7[8]	1.2 (8)	-	-
Tricresyl phosphate	$C_{21}H_{21}O_4P$	1330-78-5 (9)	368.36	40.9 (12)	39.2[12]	1.7 (12)	-	-
Water	H_2O	7732-18-5	18.02	72.8	21.8	51.0	25.5	25.5
Water	H_2O	7732-18-5	18.02	72.8 (5)	22.6[5]	50.2 (5)	25.5	25.5
Water	H_2O	7732-18-5	18.02	72.8 (6)	22.1[6]	50.7 (6)	25.5	25.5

Polar and dispersion part of the surface tension γ_L with $\gamma_L = \gamma_L^D + \gamma_L^P$

1/ Surface tension and cohesive forces

Surface tension values

Name[1]	Mol. Formula [2]	CAS #[2]	Mol. Wt. [3]	Surface Tension[4] Total	Dispersion	Polar	Acid	Base
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Diiodomethane (methylene iodide)	CH_2I_2	75-11-6	267.84	50.8	50.8	0.0	0.01	0.0
Formamide (methanamide)	CH_3NO	75-12-7	45.04	58.2 (12)	39.5(12)	18.7 (12)	2.28	39.6
Decane	$C_{10}H_{22}$	124-18-5	142.28	23.8	23.8	0.0	-	-

Name	Mol. Formula	CAS #	Mol. Wt.	Total	Dispersion	Polar	Acid	Base
Dimethyl sulfoxide (DMSO)	C_2H_6OS	67-68-5	78.13	44	36	8	0.5	32
Ethylene glycol	$C_2H_6O_2$	107-21-1	62.07	48	29	19	3.0	30.1
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Water	H_2O	7732-18-5	18.02	72.8 (5)	22.6(5)	50.2 (5)	25.5	25.5
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Polar and dispersion part of the surface tension γ_L with $\gamma_L = \gamma_L^D + \gamma_L^P$

Wettability

Laurent Vonna

1/ Surface tension and cohesive forces

2/ Wetting for a measure of the surface energy

3/ Wetting of textured surfaces

4/ Resisting wetting

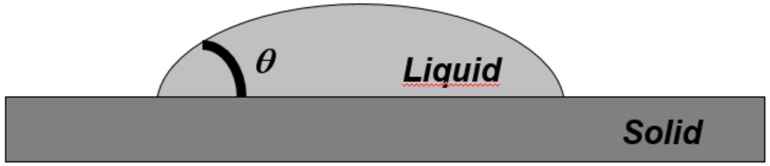
5/ Liquid-infused surfaces

« On a marché sur la lune »
Hergé, 1954

Journée thématique du GDR B2I, Paris, 12 octobre 2023
Techniques avancées de caractérisation de matière molle, biointerface ou biodispositif

2/ Wetting for a measure of the surface energy

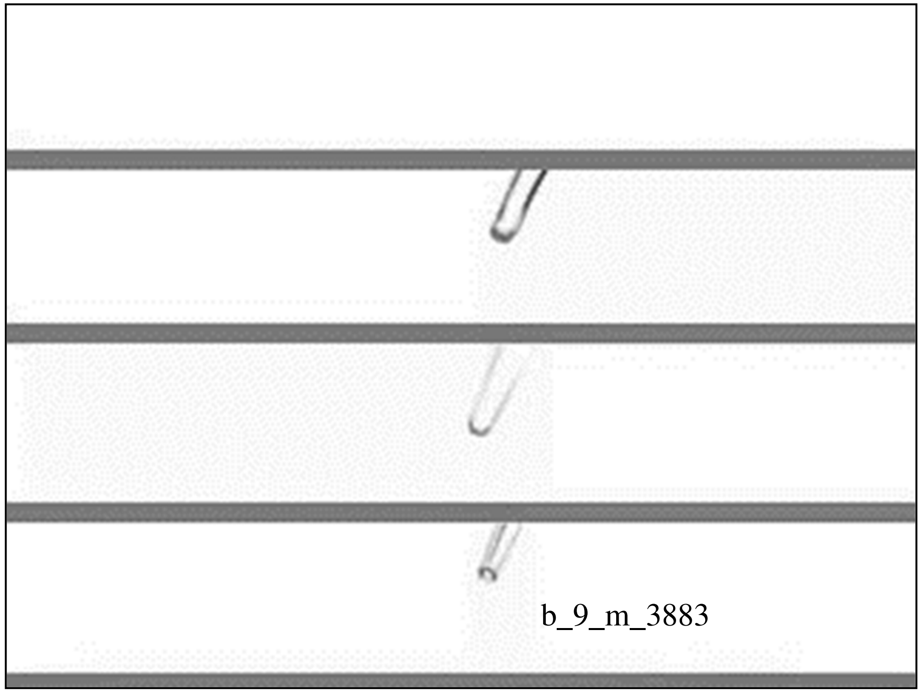
- **Contact angle value of a sessile drop is a measure of the wettability**



- Sessile droplet morphology (contact angle) is a way to characterize wettability

small contact angle = high wettability

large contact angle = low wettability



On dépose sur du téflon quatre gouttes de liquides différents : de haut en bas, de la perfluorodécaline (de tension superficielle $\gamma = 12$ mN/m), du méthylnaphtalène ($\gamma = 37$ mN/m), de l'eau ($\gamma = 72$ mN/m) et du mercure ($\gamma = 485$ mN/m). Les liquides s'étalent d'autant mieux que leur tension superficielle est faible. La condition de raccord avec le solide (ou angle de contact) est donnée par la relation de Young (éq. 1.23).

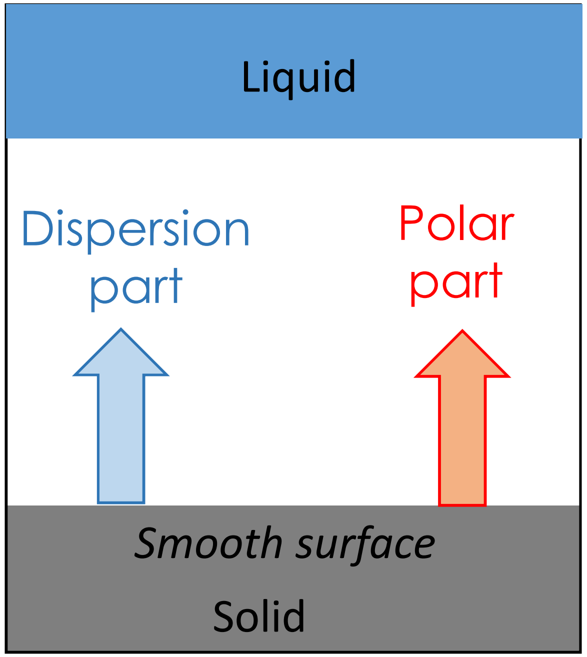
"Gouttes, bulles, perles et ondes"
Pierre-Gilles de Gennes, Françoise Brochard-Wyart, David Quéré (Editions Belin)

2/ Wetting for a measure of the surface energy

- **Determination of a surface energy**

surface energy [mJ.m^{-2}] = surface tension [mN.m^{-1}]

Solid Liquid



➡ To qualify a surface treatment

➡ To predict wetting

➡ To predict adhesion

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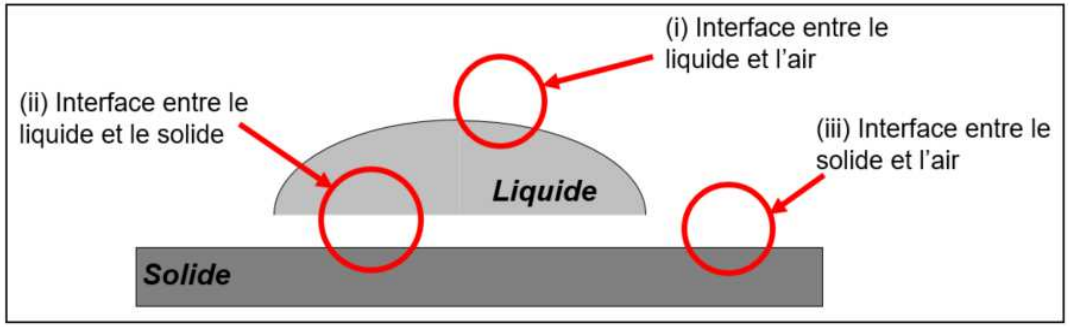
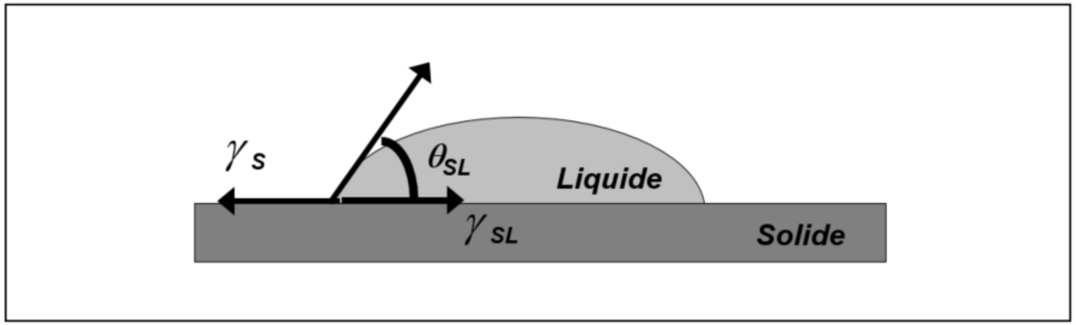




Young's equation

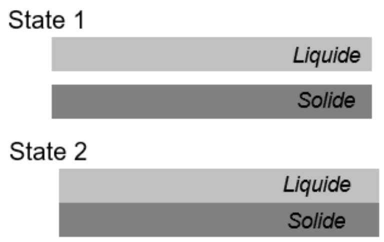
$$\gamma_S = \gamma_{SL} + \gamma_L \cos\theta_{SL}$$

2/ Wetting for a measure of the surface energy

- **Wettability/Contact angle, for the determination of the surface energy**

Dupré's adhesion energy

$$I_{SL} = \sigma_S + \sigma_L - \sigma_{SL}$$



+

Young's equation

$$\sigma_S = \sigma_{SL} + \sigma_L \cos\theta$$

Geometric mean assumption

- proposed by Good and Girifalco

$$I_{SL} = 2\ (\sigma_L)^{1/2} (\sigma_S)^{1/2}$$

- extended by Fowkes
  - additivity of the different part of the surface tension
  - geometric mean is used for these different parts

$$I_{SL} = 2\ [(\sigma_L^D)^{1/2} (\sigma_S^D)^{1/2} + (\sigma_L^P)^{1/2} (\sigma_S^P)^{1/2}]$$

→

$$I_{SL} = \sigma_L (\cos\theta + 1)$$

↓

$$(\sigma_L^D)^{1/2} (\sigma_S^D)^{1/2} + (\sigma_L^P)^{1/2} (\sigma_S^P)^{1/2} = \frac{\sigma_L (\cos\theta + 1)}{2}$$

2/ Wetting for a measure of the surface energy

- **Wettability/Contact angle, for the determination of the surface energy**

$$(\sigma_L{}^D)^{1/2}(\sigma_S{}^D)^{1/2}+(\sigma_L{}^P)^{1/2}(\sigma_S{}^P)^{1/2}=\frac{\sigma_L(\cos\theta+1)}{2}$$

- first liquid only with a dispersion part ➡ $\sigma_S{}^D=\frac{\sigma_L(\cos\theta+1)^2}{4}$
- second liquid with a dispersion AND a polar part ➡ $\sigma_S{}^P$

Surface energy of a solid

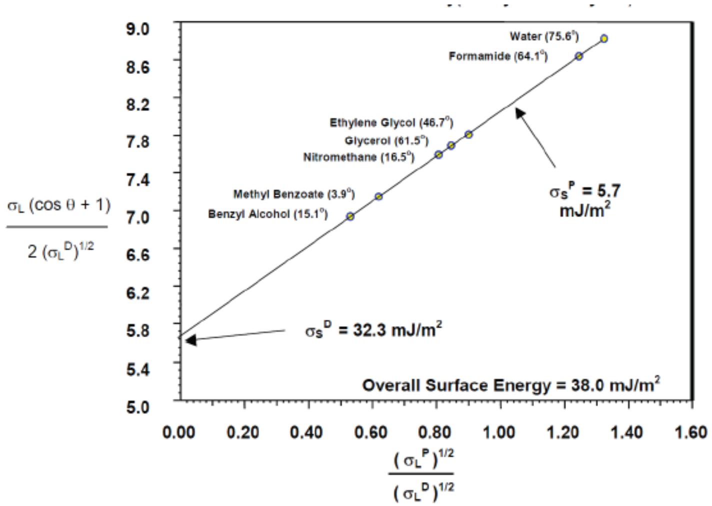
$$\sigma_S=\sigma_S{}^P+\sigma_S{}^D$$

Alternative method

$$\frac{\sigma_L(\cos\theta+1)}{2(\sigma_L{}^D)^{1/2}}=(\sigma_S{}^P)^{1/2}\frac{(\sigma_L{}^P)^{1/2}}{(\sigma_L{}^D)^{1/2}}+(\sigma_S{}^D)^{1/2}$$

Y = a X + b

With a = $(\sigma_S{}^P)^{1/2}$ and b = $(\sigma_S{}^D)^{1/2}$



https://www.kruss-scientific.com/en/know-how/glossary/surface-free-energy

2/ Wetting for a measure of the surface energy

- **Wettability/Contact angle, for the determination of the surface energy**

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Procedia Materials Science 8 (2015) 732 – 741
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International Congress of Science and Technology of Metallurgy and Materials, SAM - CONAMET 2013

Analysis of the results of surface free energy measurement of Ti6Al4V by different methods

Jonathan M. Schuster[a,b]*, Carlos E. Schvezov[a], Mario R. Rosenberger[a]

[a] Materials Institute of Misiones – IMAM (UNaM-Conicet), University of Misiones, 1552, Azara Street, 3300 Posadas, Argentina
[b] Board of Development and Technological Innovation (CEDIT), 1890 Azara Street, 3300 Posadas, Argentina

Abstract

Surface Free Energy (SFE) of solids should be calculated using theoretical models. The contact angle (CA) measurement on a surface is considered the most practical way to obtain the SFE. The results of five methods based in the models are compared: the method of Zisman (ZI), the geometric mean (GM), the harmonic mean (HM), the Lifshitz-van der Waals / Acid-Base (LW/AB) and the equation of state (ES). The SFE calculated with GM, HM and LW/AB methods change with the amount and type of liquid used, however, when water, glycerol and dimethyl sulfoxide are used together the SFE and its dispersive and polar components are similar in value for the three methods. In the case of the ES model the values of SFE change with the liquid used; finally using the ZI method the SFE values are 20% lower than the values of SFE obtained with the other methods.

Table 3. Surface free energy (mJ/m²) of a TiO_2, calculated with the different methods using different combinations of liquids

Liquids	γ_S^d	γ_S^p	γ_S	γ_S^p/γ_S
Geometric mean method				
WEGD	17.1 ± 0.6	30.2 ± 1.1	47.3 ± 0.6	0.64
WEG	11.0 ± 0.8	37.7 ± 1.6	48.8 ± 0.9	0.77
WED	17.3 ± 0.5	30.1 ± 1.1	47.4 ± 0.6	0.64
EGD	29.1 ± 0.5	13.3 ± 0.8	42.5 ± 0.3	0.31
WGD	19.5 ± 0.5	28.8 ± 1.1	48.3 ± 0.6	0.60
WD	21.2 ± 0.4	28.0 ± 1.0	49.2 ± 0.6	0.57
WG	14.4 ± 0.8	34.0 ± 1.4	48.3 ± 0.8	0.70
WE	8.5 ± 0.7	41.0 ± 1.8	49.5 ± 1.1	0.83
DG	26.3 ± 0.5	18.0 ± 0.9	44.3 ± 0.4	0.41
DE	34.5 ± 0.6	7.5 ± 0.6	42.0 ± 0.1	0.18
GE*	-	-	-	-
Harmonic mean method				
WEGD	22.3 ± 0.2	26.7 ± 0.6	49.0 ± 0.5	0.54
WEG	14.4 ± 0.4	35.9 ± 0.9	50.3 ± 0.7	0.71
WED	23.0 ± 0.2	27.2 ± 0.6	50.2 ± 0.5	0.54
EGD	29.0 ± 0.1	15.6 ± 0.4	44.6 ± 0.3	0.35
WGD	24.6 ± 0.2	26.0 ± 0.6	50.7 ± 0.5	0.51
WD	25.8 ± 0.1	27.5 ± 0.6	53.2 ± 0.5	0.52
WG	17.5 ± 0.4	32.8 ± 0.8	50.3 ± 0.6	0.65
WE	13.7 ± 0.3	36.4 ± 0.9	50.1 ± 0.7	0.73
DG	28.3 ± 0.1	17.4 ± 0.4	45.6 ± 0.3	0.38
DE	32.3 ± 0.2	9.9 ± 0.4	42.2 ± 0.1	0.23
GE*	-	-	-	-
Lifshitz-van der Waals/ Acid-Base method				
WEGD	26.9 ± 0.9	15.7 ± 1.1	42.7 ± 0.2	0.37
WEG*	-	-	-	-
WED	39.1 ± 1.2	3.4 ± 1.2	42.5 ± 0.2	0.08
EGD*	-	-	-	-
WGD	20.5 ± 0.8	23.4 ± 1.1	43.9 ± 0.4	0.53

Ref: W: Water – E: Ethylene glycol – G: Glycerol – D: Dimethyl sulfoxide
*result without physical meaning

- five different methods: the Zisman method, the geometric mean method, the harmonic mean method, the Lifshitz-van der Waals / Acid-Base method and the equation of state method
- calculated values of σ_S which are similar, between 42 and 50 mJ/m²

2/ Wetting for a measure of the surface energy

- **Wettability/Contact angle, for the determination of the surface energy**

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International Congress of Science and Technology of Metallurgy and Materials, SAM - CONAMET 2013

Analysis of the results of surface free energy measurement of Ti6Al4V by different methods

Jonathan M. Schuster[a,b]*, Carlos E. Schvezov[a], Mario R. Rosenberger[a]

[a] Materials Institute of Misiones – IMAM (UNaM-Conicet), University of Misiones, 1552, Azara Street, 3300 Posadas, Argentina
[b] Board of Development and Technological Innovation (CEDIT), 1890 Azara Street, 3300 Posadas, Argentina

Abstract

Surface Free Energy (SFE) of solids should be calculated using theoretical models. The contact angle (CA) measurement on a surface is considered the most practical way to obtain the SFE. The results of five methods based in the models are compared: the method of Zisman (ZI), the geometric mean (GM), the harmonic mean (HM), the Lifshitz-van der Waals / Acid-Base (LW/AB) and the equation of state (ES). The SFE calculated with GM, HM and LW/AB methods change with the amount and type of liquid used, however, when water, glycerol and dimethyl sulfoxide are used together the SFE and its dispersive and polar components are similar in value for the three methods. In the case of the ES model the values of SFE change with the liquid used; finally using the ZI method the SFE values are 20% lower than the values of SFE obtained with the other methods.

Table 3. Surface free energy (mJ/m^2) of a TiO_2, calculated with the different methods using different combinations of liquids

Liquids	$\gamma_S{}^d$	$\gamma_S{}^p$	γ_S	γ_S^p/γ_S
Geometric mean method				
WEGD	17.1 ± 0.6	30.2 ± 1.1	47.3 ± 0.6	0.64
WEG	11.0 ± 0.8	37.7 ± 1.6	48.8 ± 0.9	0.77
WED	17.3 ± 0.5	30.1 ± 1.1	47.4 ± 0.6	0.64
EGD	29.1 ± 0.5	13.3 ± 0.8	42.5 ± 0.3	0.31
WGD	19.5 ± 0.5	28.8 ± 1.1	48.3 ± 0.6	0.60
WD	21.2 ± 0.4	28.0 ± 1.0	49.2 ± 0.6	0.57
WG	14.4 ± 0.8	34.0 ± 1.4	48.3 ± 0.8	0.70
WE	8.5 ± 0.7	41.0 ± 1.8	49.5 ± 1.1	0.83
DG	26.3 ± 0.5	18.0 ± 0.9	44.3 ± 0.4	0.41
DE	34.5 ± 0.6	7.5 ± 0.6	42.0 ± 0.1	0.18
GE*	-	-	-	-
Harmonic mean method				
WEGD	22.3 ± 0.2	26.7 ± 0.6	49.0 ± 0.5	0.54
WEG	14.4 ± 0.4	35.9 ± 0.9	50.3 ± 0.7	0.71
WED	23.0 ± 0.2	27.2 ± 0.6	50.2 ± 0.5	0.54
EGD	29.0 ± 0.1	15.6 ± 0.4	44.6 ± 0.3	0.35
WGD	24.6 ± 0.2	26.0 ± 0.6	50.7 ± 0.5	0.51
WD	25.8 ± 0.1	27.5 ± 0.6	53.2 ± 0.5	0.52
WG	17.5 ± 0.4	32.8 ± 0.8	50.3 ± 0.6	0.65
WE	13.7 ± 0.3	36.4 ± 0.9	50.1 ± 0.7	0.73
DG	28.3 ± 0.1	17.4 ± 0.4	45.6 ± 0.3	0.38
DE	32.3 ± 0.2	9.9 ± 0.4	42.2 ± 0.1	0.23
GE*	-	-	-	-
Lifshitz-van der Waals/ Acid-Base method				
WEGD	26.9 ± 0.9	15.7 ± 1.1	42.7 ± 0.2	0.37
WEG*	-	-	-	-
WED	39.1 ± 1.2	3.4 ± 1.2	42.5 ± 0.2	0.08
EGD*	-	-	-	-
WGD	20.5 ± 0.8	23.4 ± 1.1	43.9 ± 0.4	0.53

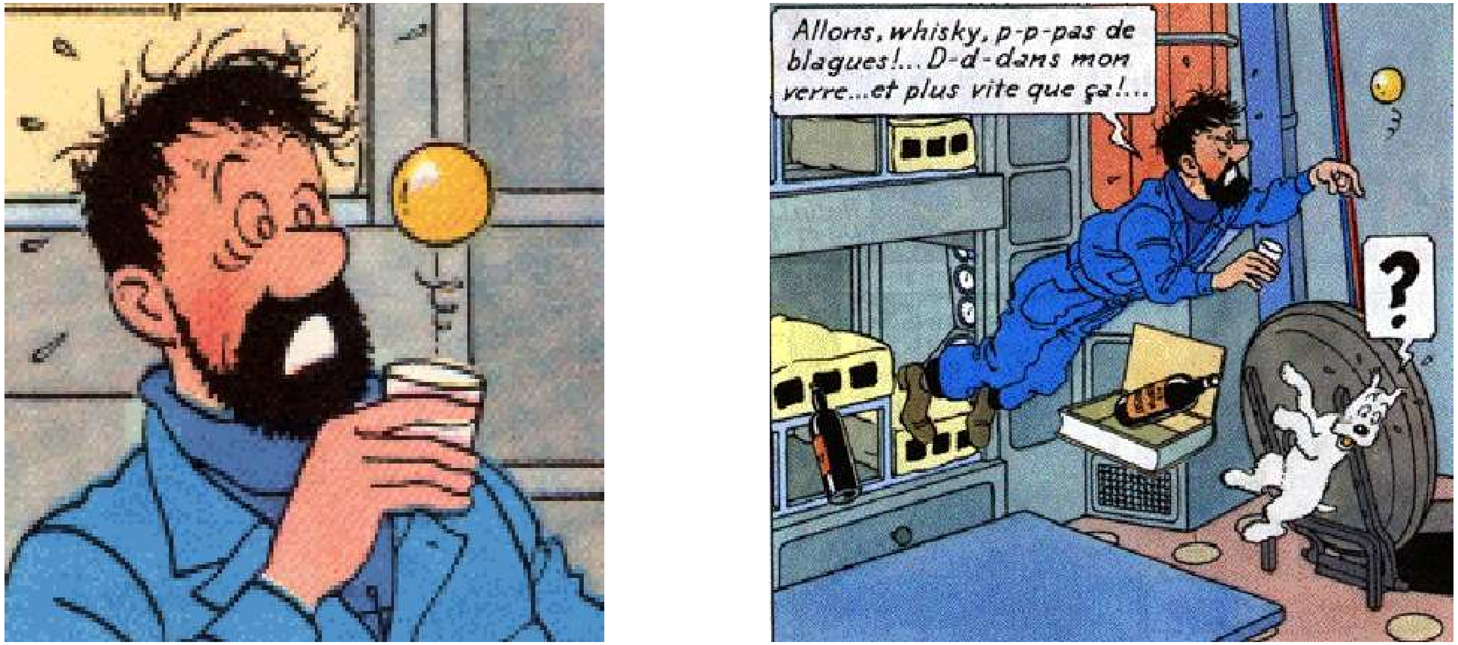
Ref: W: Water – E: Ethylene glycol – G: Glycerol – D: Dimethyl sulfoxide
*result without physical meaning

- Determining the surface energy of a solid using the contact angle suppose
  - to choose a method
  - to know the polar and dispersion part of the surface tension of the test liquids
  - to use liquids that are compatible with the solid
  - To avoid rough and porous substrate

2/ Wetting for a measure of the surface energy

- **Wettability/Contact angle, for the determination of the surface energy**

Hergé’s assumption



« On a marché sur la lune », Hergé, 1954

2/ Wetting for a measure of the surface energy

Wringing out Water on the ISS - for Science!
https://www.youtube.com/watch?v=o8TssbmY-GM
Canadian Space Agency (2013)

2/ Wetting for a measure of the surface energy

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Wettability

Laurent Vonna

1/ Surface tension and cohesive forces

2/ Wetting for a measure of the surface energy

3/ Wetting of textured surfaces

4/ Resisting wetting

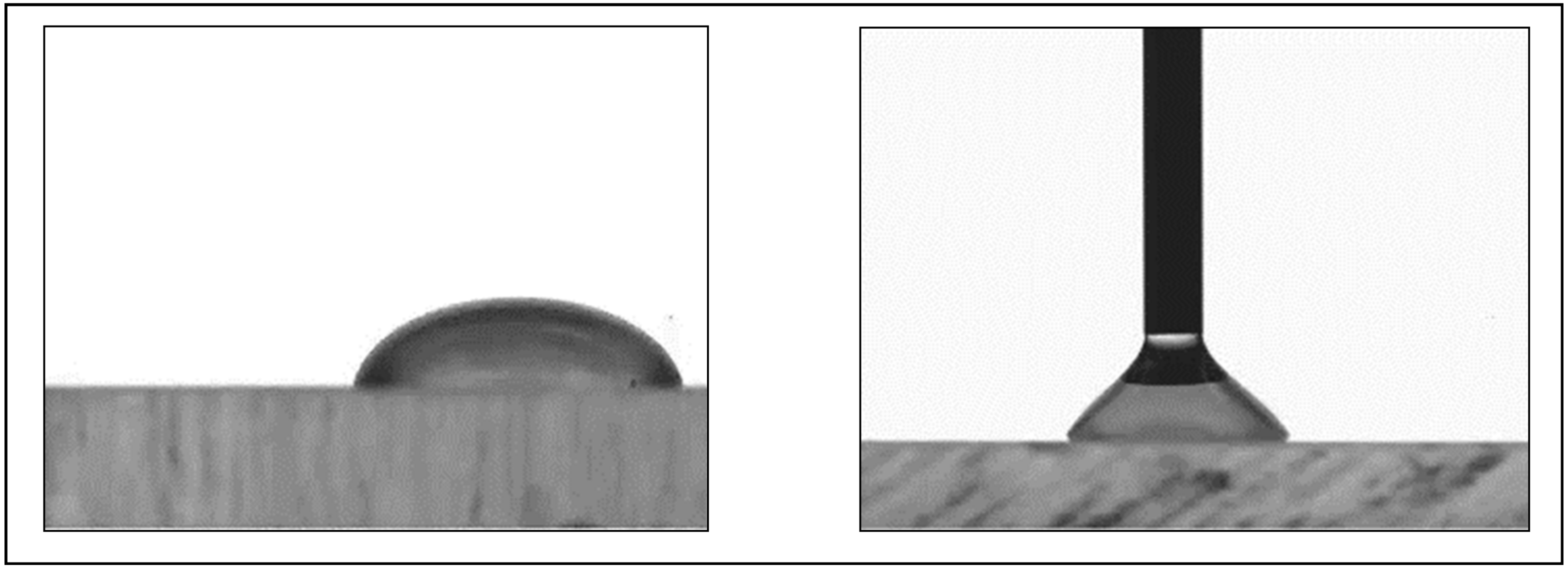
5/ Liquid-infused surfaces

https://www.usgs.gov/

Journée thématique du GDR B2I, Paris, 12 octobre 2023
Techniques avancées de caractérisation de matière molle, biointerface ou biodispositif

3/ Wetting of textured surfaces

• The contact angle hysteresis



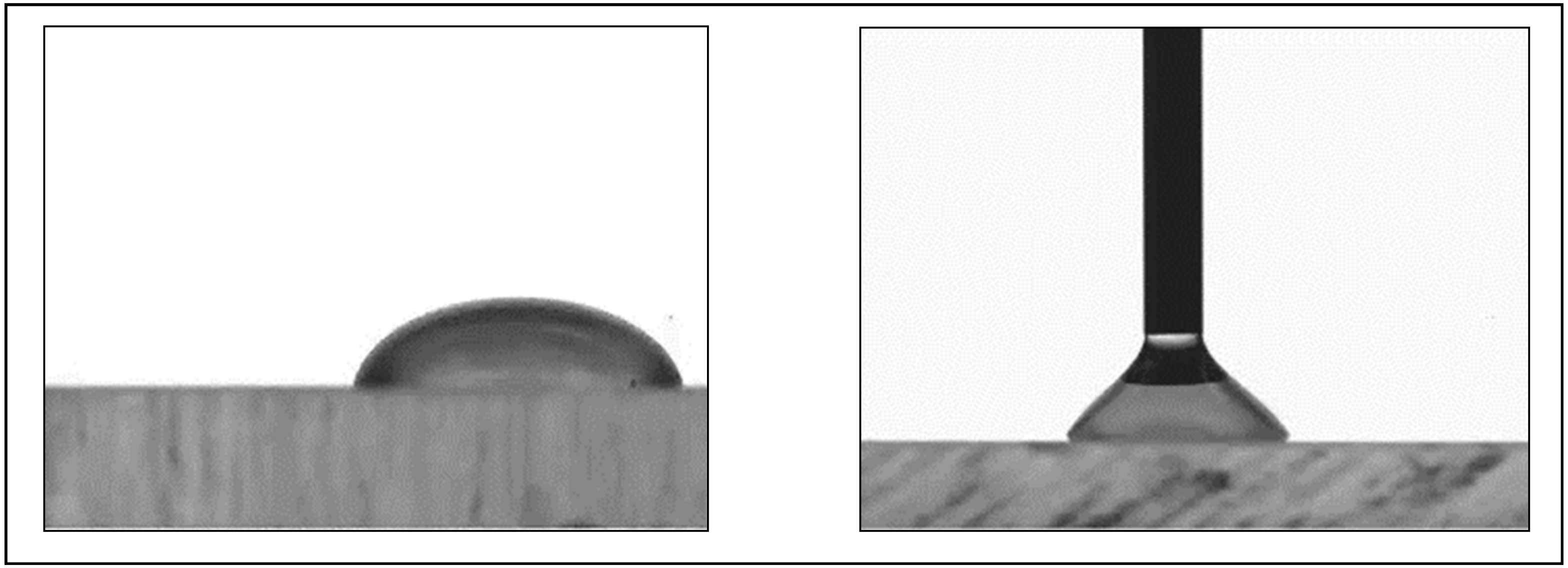
"Gouttes, bulles, perles et ondes" Pierre-Gilles de Gennes, Françoise Brochard-Wyart, David Quéré (Éditions Belin)

$$H = \cos\,\theta_a - \cos\,\theta_r$$

- H gives an idea of the adhesion of a liquid on a surface
- The pinning is produced by
  - Chemical heterogeneities
  - Physical heterogeneities

3/ Wetting of textured surfaces

- **The contact angle hysteresis**



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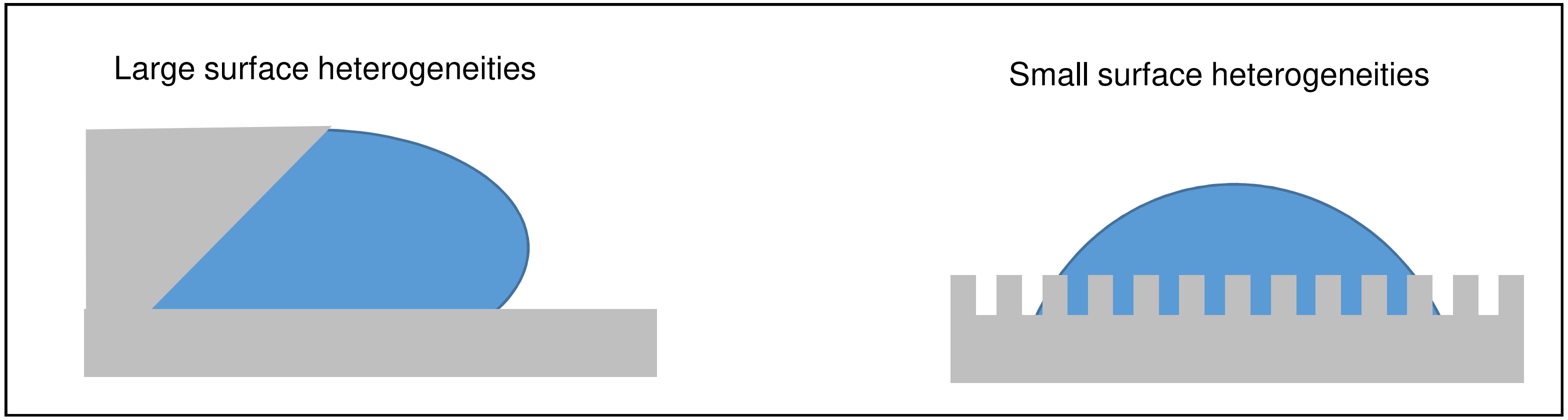
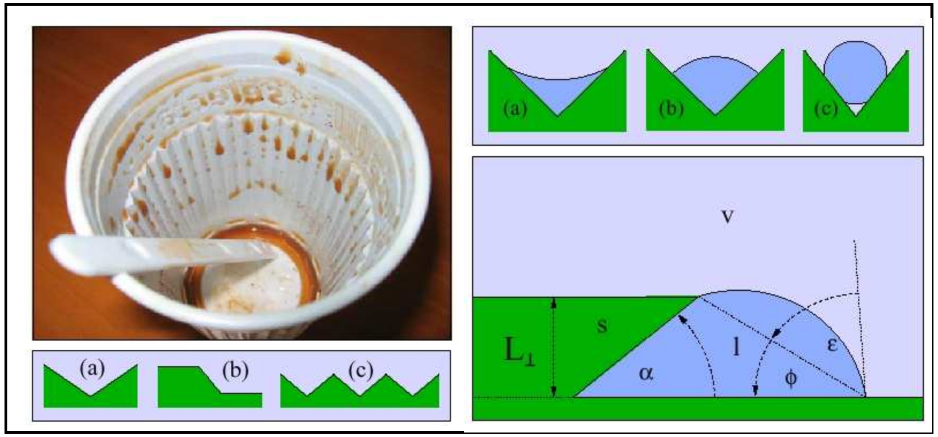
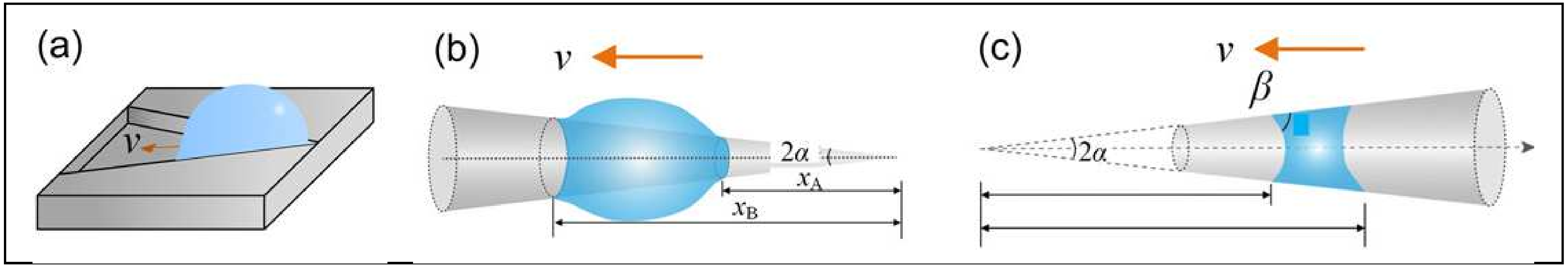


3/ Wetting of textured surfaces

- **Large asymmetric structures for directed wetting**



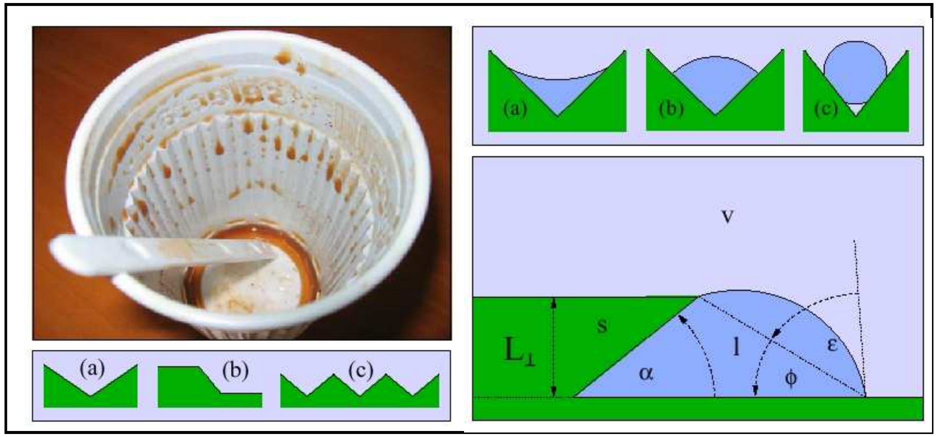
« Blobs,channels and “cigars ”:Morphologies of liquids at a step » M.Brinkmann and R.Blossey
Eur.Phys.J.E 14 ,79 –89 (2004)



« Bioinspired materials for droplet manipulation: Principles, methods and applications »
Jinkai Xu, Siyu Xiu, Zhongxu Lian, Huadong Yu, Jiaji Cao, Droplets, 2022, https://doi.org/10.1002/dro2.12Citations: 7

3/ Wetting of textured surfaces

- **Large asymmetric structures for directed wetting**



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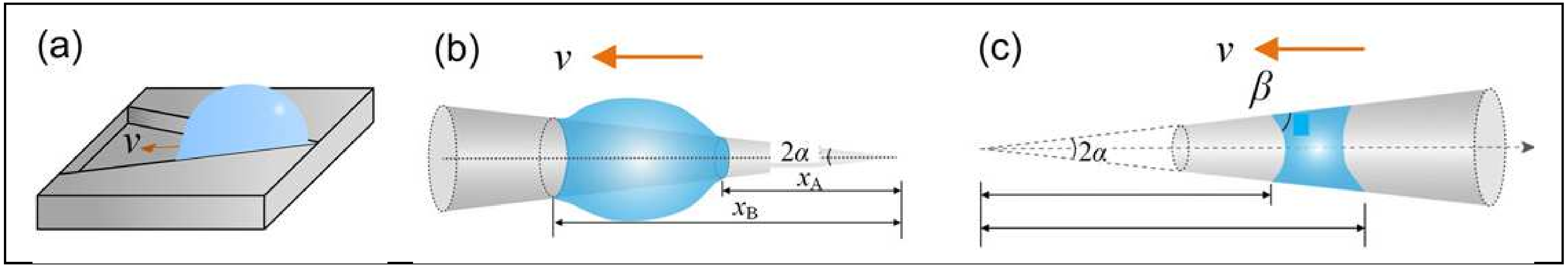

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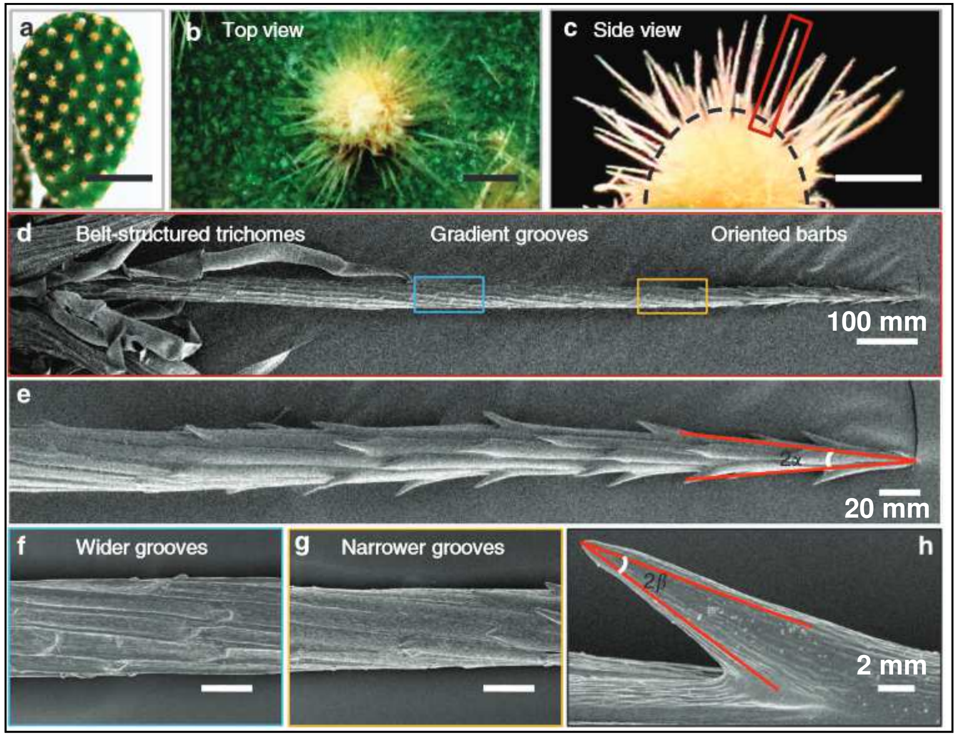
3/ Wetting of textured surfaces

- **Large asymmetric structures for directed wetting**

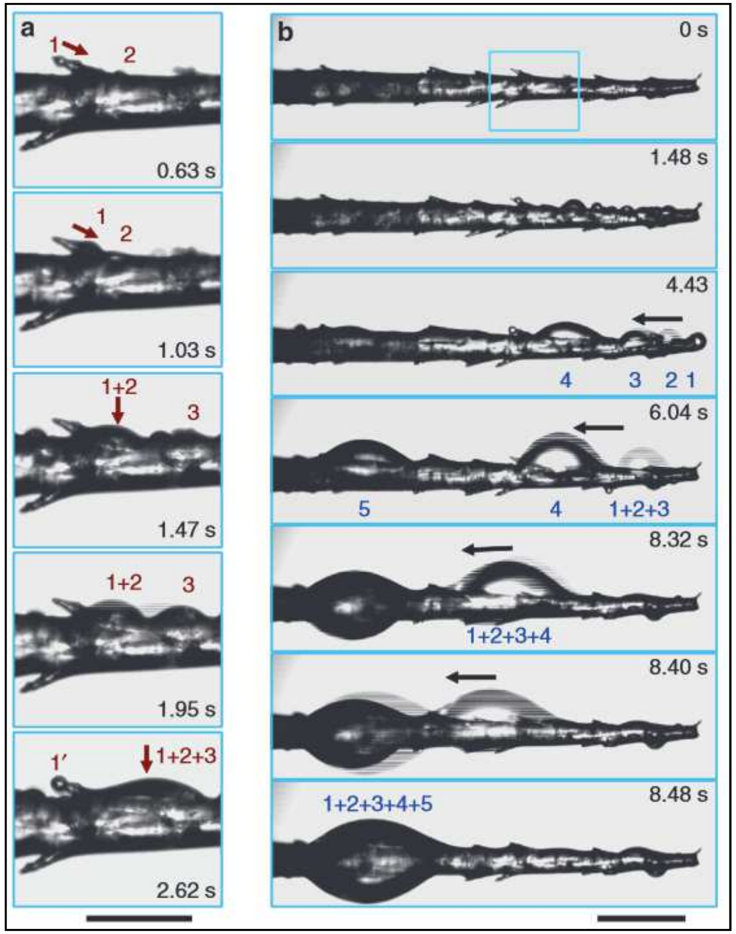
The cactus *Opuntia microdasys*



Appearance and surface structures of the cactus. (a) Optical image of a plant of O. microdasys stem covered with well-distributed clusters of spines and trichomes. (b,c) Magnified optical images of a single cluster with spines growing from the trichomes in the top (b) and side (c) view. (d) SEM image of a single spine divided into three regions, the tip (e) with an apex angle (2a) and oriented barbs, the middle (f,g) with gradient grooves, and the base with belt-structured trichomes. (f,g) Magnified images of regions near the base and tip of the cactus spine, respectively. The microgrooves near the base are wider and sparser than those near the tip. (h) Magnified image of a single barb with an apex angle (2b) covering the tip of the spine (e). Scale bars, 5 cm (a), 500 mm (b,c), 100 mm (d), 20 mm (e–g) and 2 mm (h).

J. Ju, H. Bai, Y. Zheng, Ti. Zhao, R. Fang, and L. Jianga. A multi-structural and multi-functional integrated fog collection system in cactus. Nat Commun. 3: 1247, 2012.

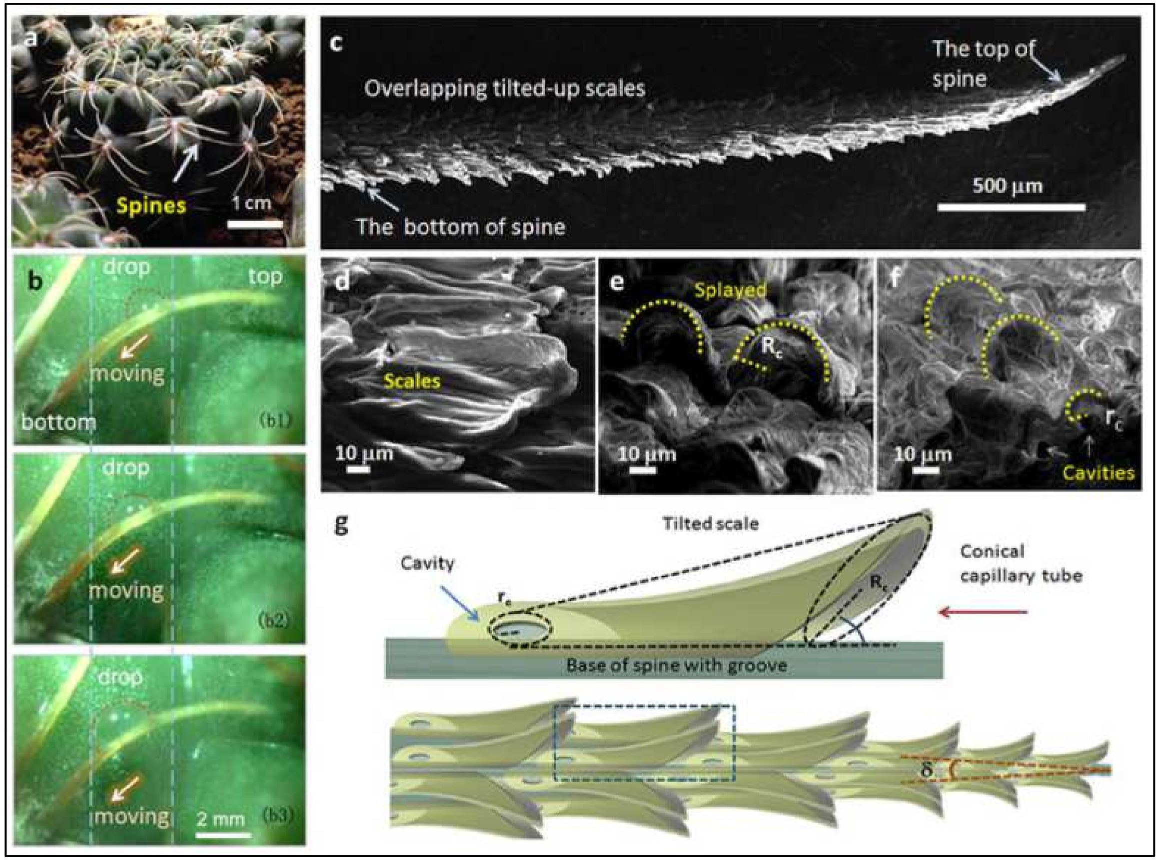
In situ optical microscopic observation of the detailed water collection process on a single horizontal spine and two adjacent spines with trichomes. (a) Continuous deposition of the water drops on the barbs and the spine. Initially, tiny water drops 1 and 2 were deposited concomitantly on the barb and the spine, respectively. Drop 1 moved toward the base of the barb with the volume increasing and coalesced with drop 2, forming larger drop 1+2. As the deposition proceeded, drop 1+2 further coalesced with drop 3 on the adjacent barb. A new cycle started when a subsequent small water drop 1 0 deposited at the same location of initial drop 1. (b) Directional collection of the water drops on the spine. The deposited drop (1) and the coalesced drops (2–4) combine, moving directionally along the spine (black arrows) to form a large drop (1+2+3+4+5).

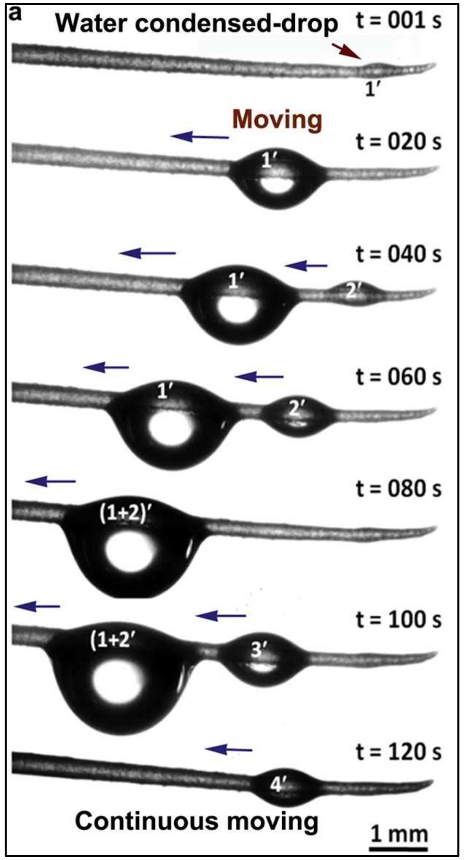


3/ Wetting of textured surfaces

• Large asymmetric structures for directed wetting

The cactus *Gymnocalycium baldianum*

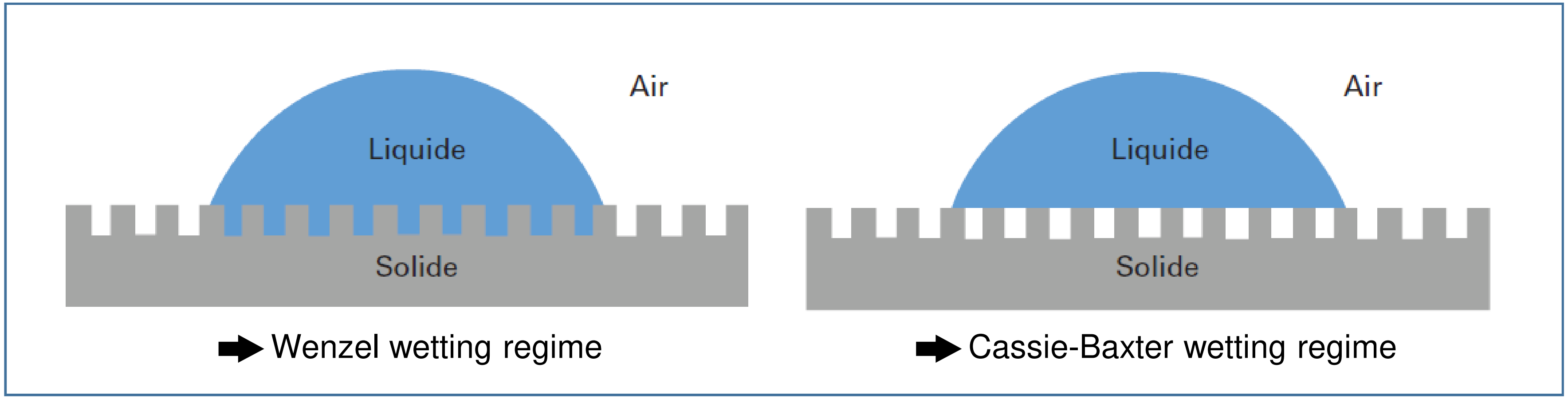




« Effective directional self-gathering of drops on spine of cactus with splayed capillary arrays » Chengcheng Liu, Yan Xue, Yuan Chen, Yongmei Zheng
Scientific Reports 5, : 17757 (**2015**)

3/ Wetting of textured surfaces

- **Small surface heterogeneities**



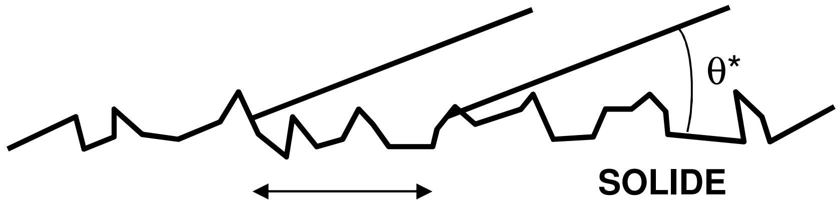
Intimate liquid/solid interface

Composite interface with air trapped in between the liquid and the solid

3/ Wetting of textured surfaces

- **Small surface heterogeneities**

The Wenzel wetting regime



r = rugosity factor (r = 1 for a smooth surface)

$dE = r\,(\gamma_{SL} - \gamma_S)_1\,dx + r\,\gamma_L\,dx \cos\theta^*$

$\cos\theta^* = r\cos\theta_E$

For an hydrophilic solid ($\theta_E < 90°$) on a $\theta^* < \theta_E$

For a hydrophobic solid ($\theta_E > 90°$) on a $\theta^* > \theta_E$

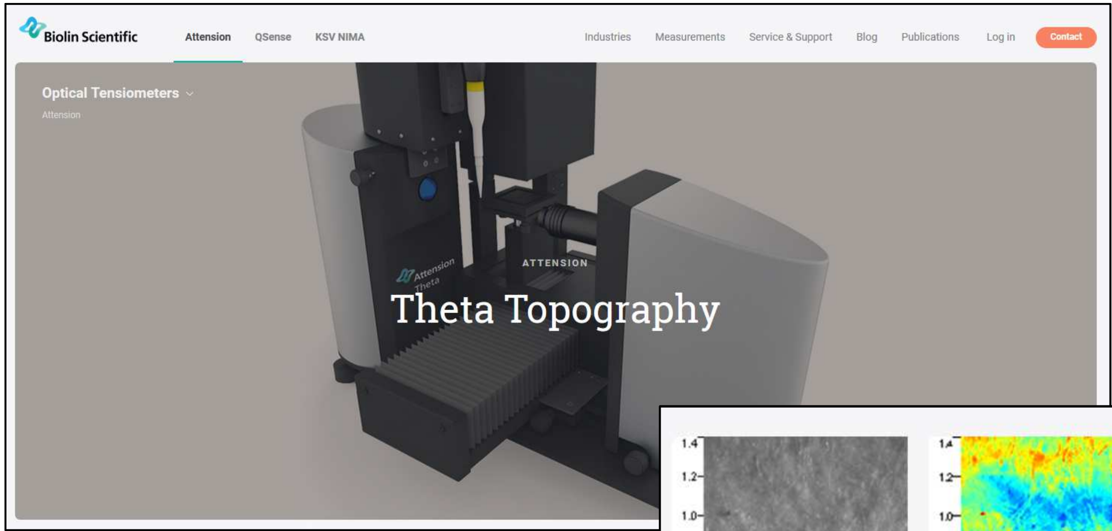
Roughness modifies the contact angle !

Roughness modifies the calculation of the surface energy

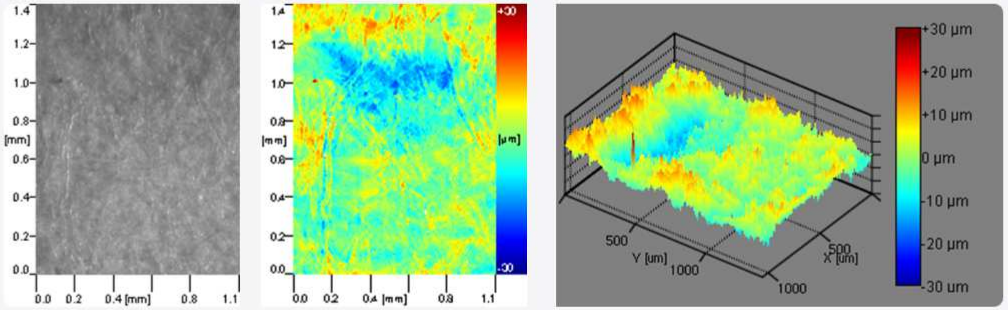
3/ Wetting of textured surfaces

- **Small surface heterogeneities**

The Wenzel wetting regime ➡ **Considering r for a correction of the contact angle?**



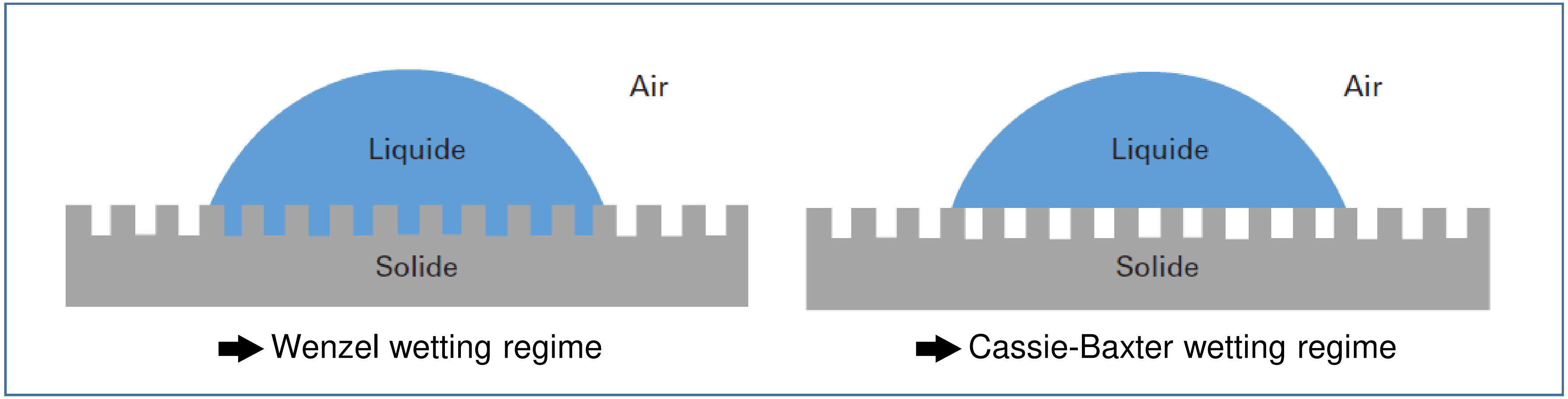
$$\cos\theta_E = (1/r) \cos \theta^*$$



The optical image (left), 2D representation (middle), and 3D representation (right) of a paper sample measured with the Attension® Topography.

3/ Wetting of textured surfaces

- **Small surface heterogeneities**



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Composite interface with air trapped in between the liquid and the solid

3/ Wetting of textured surfaces

- **Superhydrophobicity + superoleophobicity = superomniphobicity**

Neinhuis and Barthlott (1997)

Annals of Botany **79**: 667–677, 1997

Characterization and Distribution of Water-repellent, Self-cleaning Plant Surfaces

C. NEINHUIS and W. BARTHLOTT

Botanisches Institut und Botanischer Garten der Universität, Meckenheimer Allee 170, D-53115 Bonn, Germany

Received: 23 October 1996 Accepted: 23 January 1997

During the last 20 years, a wealth of data dealing with scanning electron microscopy of plant surfaces has been published. The ultrastructure of epidermal surfaces has been investigated with respect to taxonomic, as well as functional aspects. Within the latter, water-repellency has received much attention and has been well documented. Water-repellency is based on surface roughness caused by different microstructures (trichomes, cuticular folds and wax crystals), together with the hydrophobic properties of the epicuticular wax. In addition, contaminating particles are carried away by water droplets, resulting in a cleaned surface (Lotus-effect). Therefore, rough, waxy leaves are not only water-repellent but anti-adhesive with respect to particulate contamination. Based on 200 water-repellent plant species, the present paper surveys micromorphological characteristics of anti-adhesive plant surfaces. Leaves that are permanently water-repellent can be differentiated by distictively convex to papillose epidermal cells and a very dense layer of epicuticular waxes. Leaves that are water-repellent for only a limited period of time have only slightly convex epidermal cells and often have a less dense wax layer. Finally, an overview is given on the occurrence of water-repellency among different life forms and within different habitats. Water-repellency is concentrated in herbaceous species, while it is rare in trees. Among different habitats, subtropical regions, wetlands and disturbed areas appear to have more species with water-repellent leaves. The importance of roughness and water-repellency, respectively, as the basis of an anti-adhesive, self-cleaning surface, in comparison to other functions of microstructures, is discussed.

➡ High contact angles

➡ Low adhesion

➡ Surface micro and nanotexture

TABLE 1. *Contact angles (CA), epidermal relief and epicuticular wax crystals (ECW) of the investigated species in respect to the characterization of water repellent surfaces*

Species	CA (°)	Epidermis	ECW
Abies alba	157	Convex	Tubules
Acacia dealbata	160	Papillose	Tubules
Acacia glaucoptera	162	Convex	Platelets
Acantholimon spec.	158	Papillose	Ribbons
Adiantum andicola	162	Convex	Platelets
Aethionema grandiflora	159	Papillose	Coiled rodlets
*Agathis australis**	158	Convex	Tubules
*Agathis robusta**	159	Convex	Tubules
*Akebia quinata**	158	Convex	Tubules
*Akebia trifoliata**	160	Convex	Tubules
Alchemilla diplophylla	162	Papillose	Tubules
Allium cyathophorum	161	Convex	Platelets
Alopecurus pratensis	158	Convex	Platelets
Alstroemeria aurantiaca	161	Convex	Platelets
*Amelanchier lamarckii**	158	Convex	Tubules
*Amherstia nobilis**	160	Convex	Platelets
*Apocynum cannabinum**	153	Convex	Platelets
Aquilegia chrysantha	158	Papillose	Tubules
Aquilegia longissima	158	Papillose	Tubules
Argemone mexicana	157	Convex	Tubules
*Aristolochia cymbifera**	160	Convex	Rodlets
*Aristolochia grandiflora**	161	Convex	Rodlets
Artemisia tridentata	—	Hairy	—
Arthropodium cirrhatum	162	Convex	Platelets
Asphodeline lutea	155	Convex	Rodlets
Asphodelus aestivus	158	Convex	Rodlets
Astragalus falcatus	160	Papillose	Platelets
Astragalus ponticus	157	Papillose	Platelets
Astragalus galegiformis	159	Papillose	Platelets
Atriplex patula	158	Convex	Platelets
Azolla filiculoides	—	Papillose	Rodlets
*Belamcanda chinensis**	160	Papillose	Platelets
*Berberis thunbergii**	157	Convex	Tubules
*Bomarea spec.**	169	Convex	Platelets
Brassica oleracea	161	± Smooth	Dendritic
*Buxus sempervirens**	159	Convex	Coiled rodlets
*Callistemon sieberi**	—	Hairy	—
*Callistemon citrinus**	—	Hairy	—
Canarina canariensis	158	Convex	Platelets/threads
Canna glauca	159	Papillose	Platelets
Cercidiphyllum japonicum	152	Papillose	Tubules
Cladium mariscus	150	Convex	Platelets
Cleome arborea	159	Papillose	Threads
Colocasia esculenta	164	Papillose	Platelets
Comarum palustre	159	Convex	Ribbons
Convolvulus cneorum	—	Hairy	Platelets

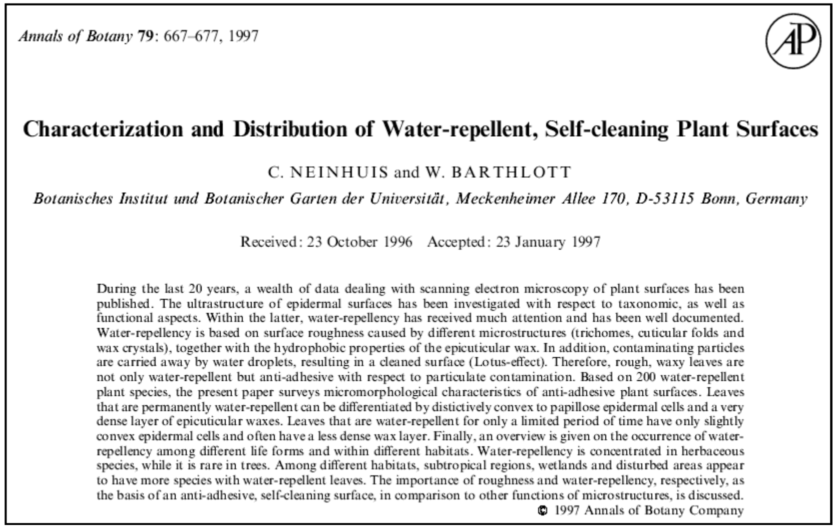
Barthlott W. and C. Neinhuis "Purity of the sacred lotus, or escape from contamination in biological surfaces" (Planta (1997) 202: 1)

C. Neinhuis and Barthlott W. "Characterization and Distribution of Water-repellent, Self-cleaning Plant Surfaces" Annals of Botany, Volume 79, Issue 6, June 1997, Pages 667–677, https://doi.org/10.1006/anbo.1997.0400

3/ Wetting of textured surfaces

- **Superhydrophobicity + superoleophobicity = superomniphobicity**

Neinhuis and Barthlott (1997)



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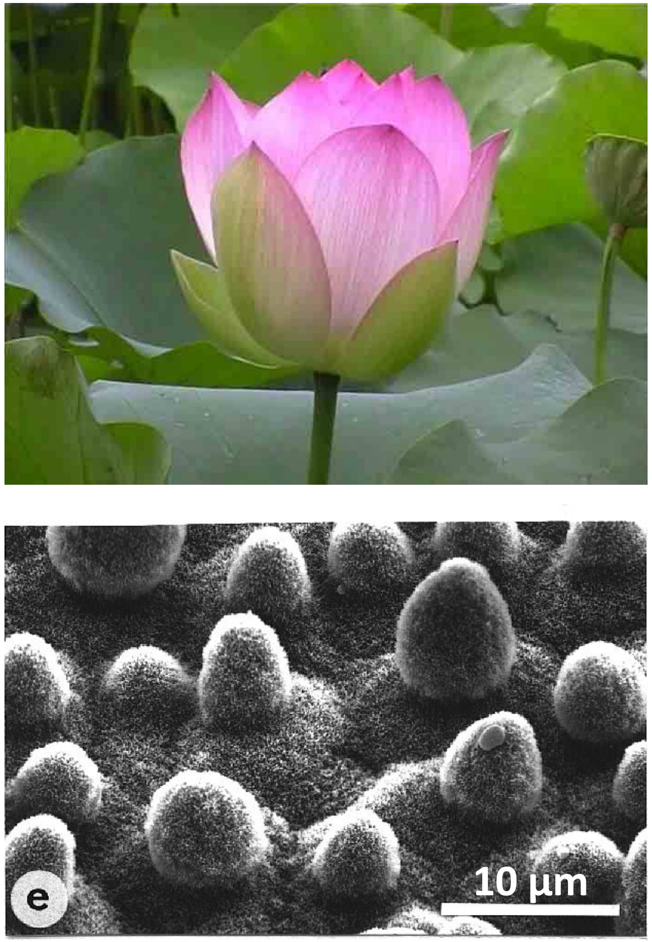

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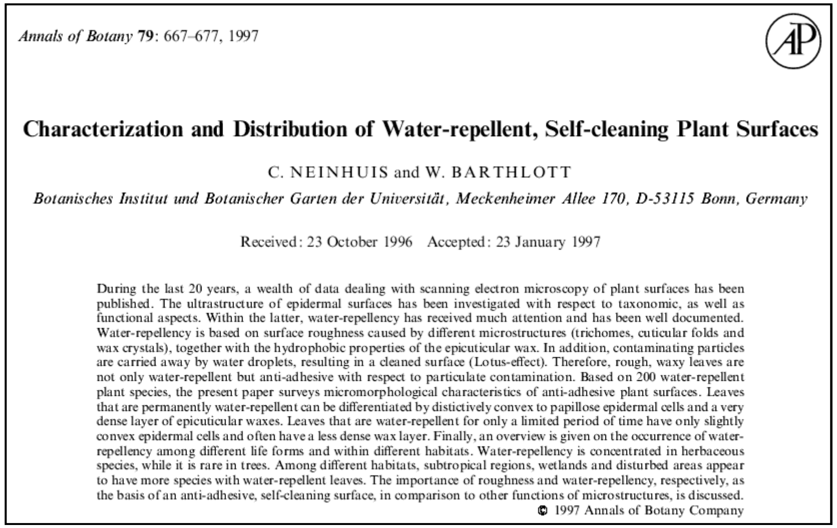

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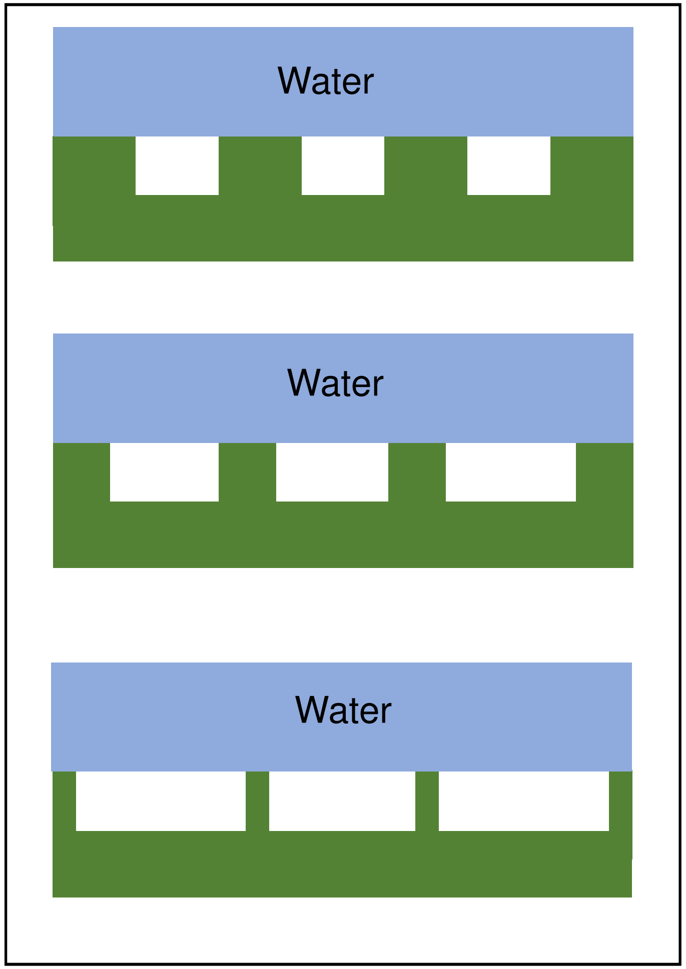


➡ High contact angles

➡ Low adhesion

➡ Surface micro and nanotexture

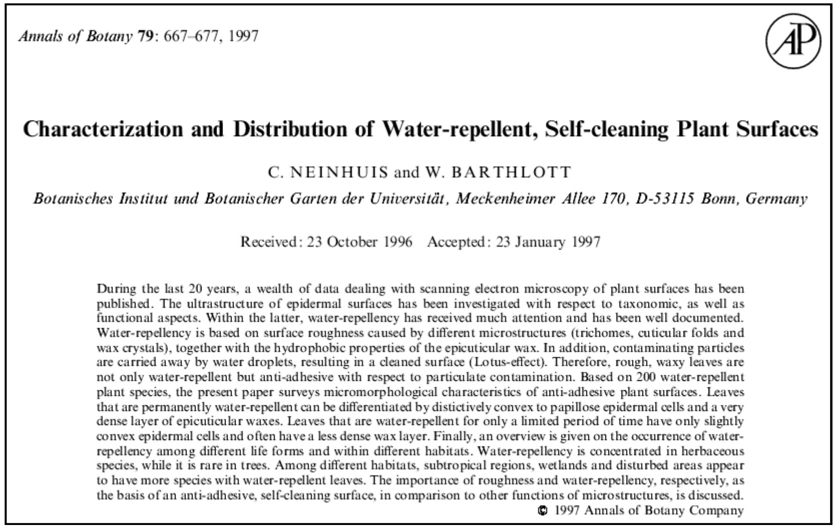
Barthlott W. and C. Neinhuis "Purity of the sacred lotus, or escape from contamination in biological surfaces" (Planta (1997) 202: 1)

C. Neinhuis and Barthlott W. "Characterization and Distribution of Water-repellent, Self-cleaning Plant Surfaces" Annals of Botany, Volume 79, Issue 6, June 1997, Pages 667–677, https://doi.org/10.1006/anbo.1997.0400

3/ Wetting of textured surfaces

- **Superhydrophobicity + superoleophobicity = superomniphobicity**

Neinhuis and Barthlott (1997)



Annals of Botany **79**: 667–677, 1997

Characterization and Distribution of Water-repellent, Self-cleaning Plant Surfaces

C. NEINHUIS and W. BARTHLOTT

Botanisches Institut und Botanischer Garten der Universität, Meckenheimer Allee 170, D-53115 Bonn, Germany

Received: 23 October 1996 Accepted: 23 January 1997

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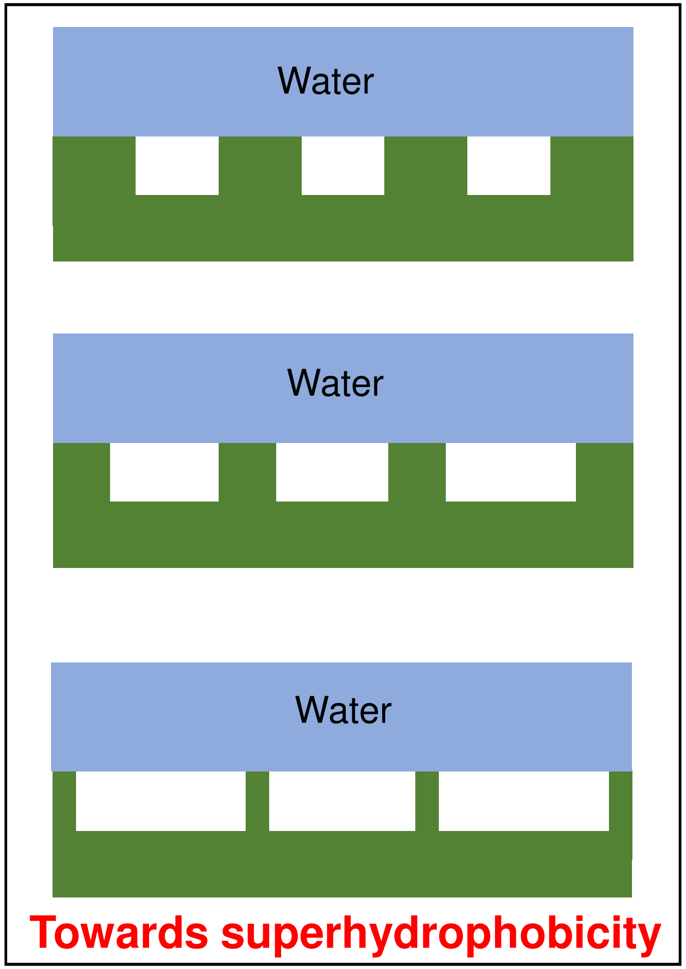

The Cassie Baxter wetting regime (1945)

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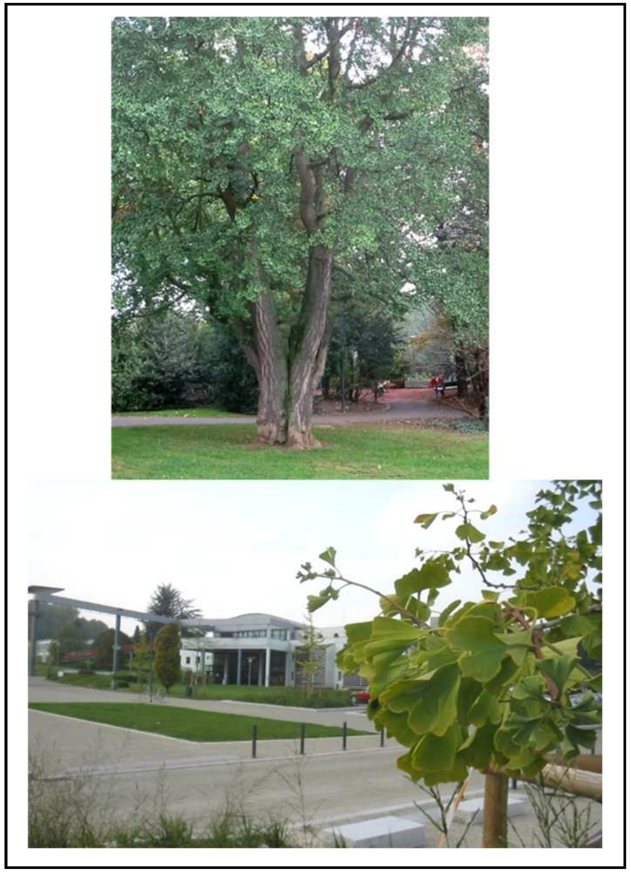
Ginkgo Biloba



« Biomimetic Approach for the Elaboration of Highly Hydrophobic Surfaces: Study of the Links between Morphology and Wettability »
Quentin Legrand, Stephane Benayoun and Stephane Valette
Biomimetics 2021, 6(2), 38; https://doi.org/10.3390/biomimetics6020038

***Gerris remigis* (2014)**

"Biophysics: Water-repellent legs of water striders"
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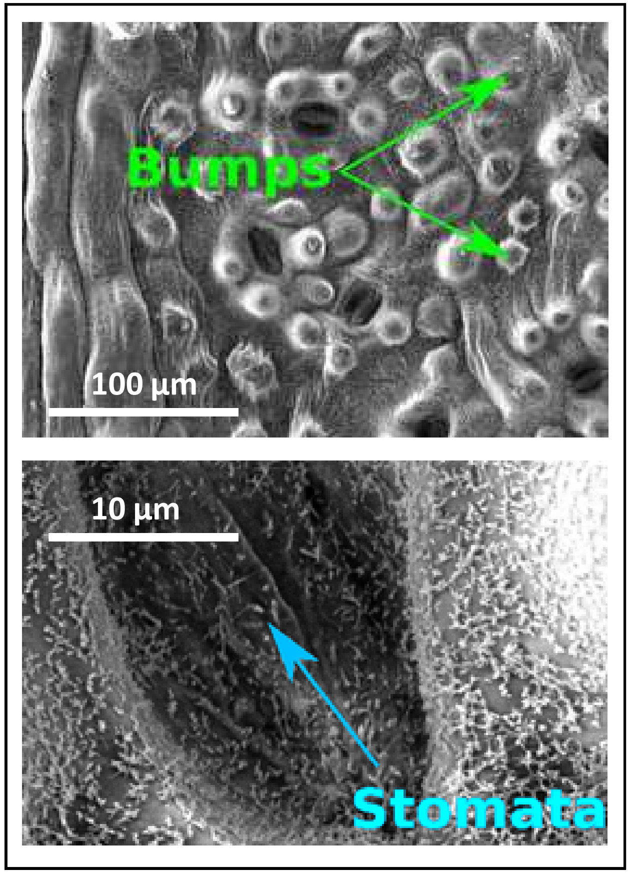

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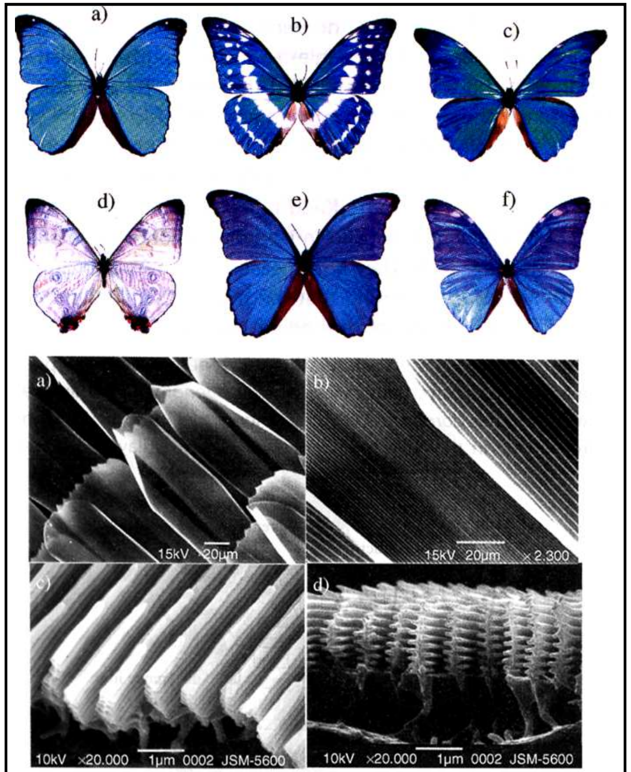
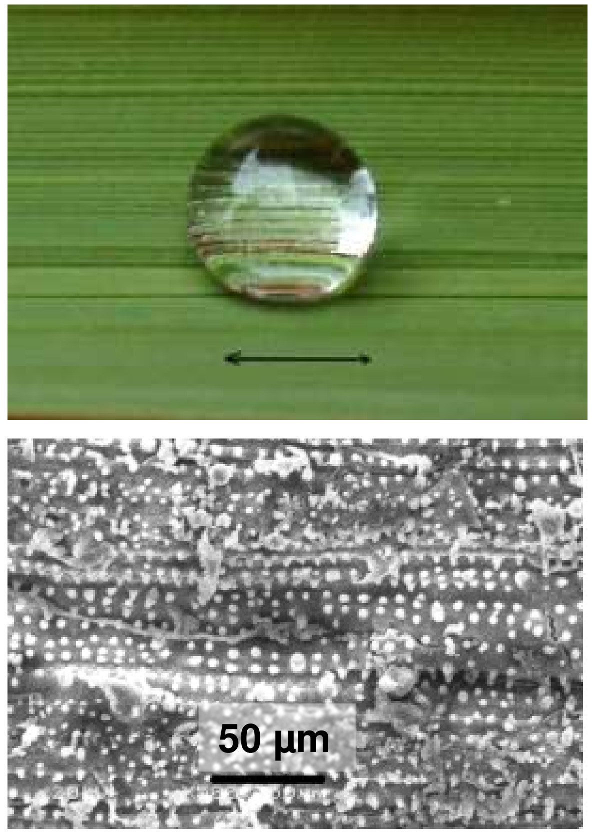


Figure 9. Scanning electron microscopic images of a,b) cover and ground scales of *M. didius*, and c,d) cross-sections of its ground scale.[29,30] The bars are a) 20, b) 10, c) 1, and d) 1 µm.

« Directional adhesion of superhydrophobic butterfly wings » Yongmei Zheng, Xuefeng Gao and Lei Jiang, Soft Matter, 2007,3, 178-182

Rice leaf (2007)



« Biomimic from the superhydrophobic plant leaves in nature: Binary structure and unitary structure » Zhiguang Guo, Weimin Liu, Plant Science Volume 172, Issue 6, June 2007, Pages 1103-1112

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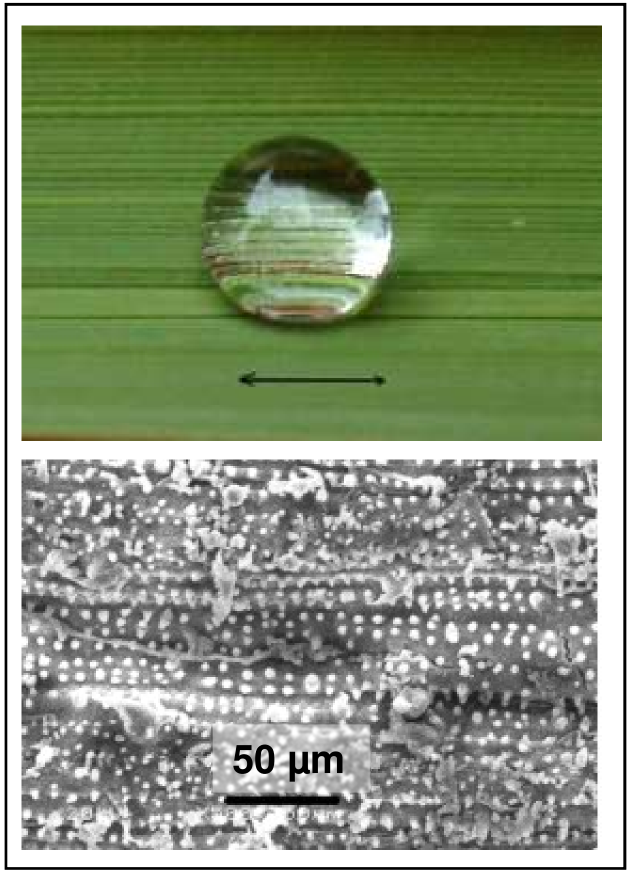

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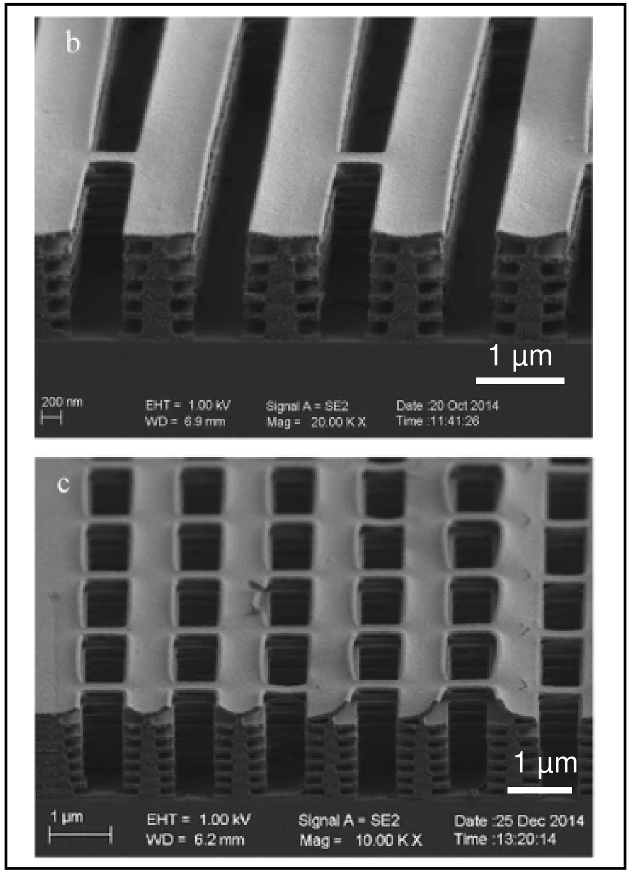
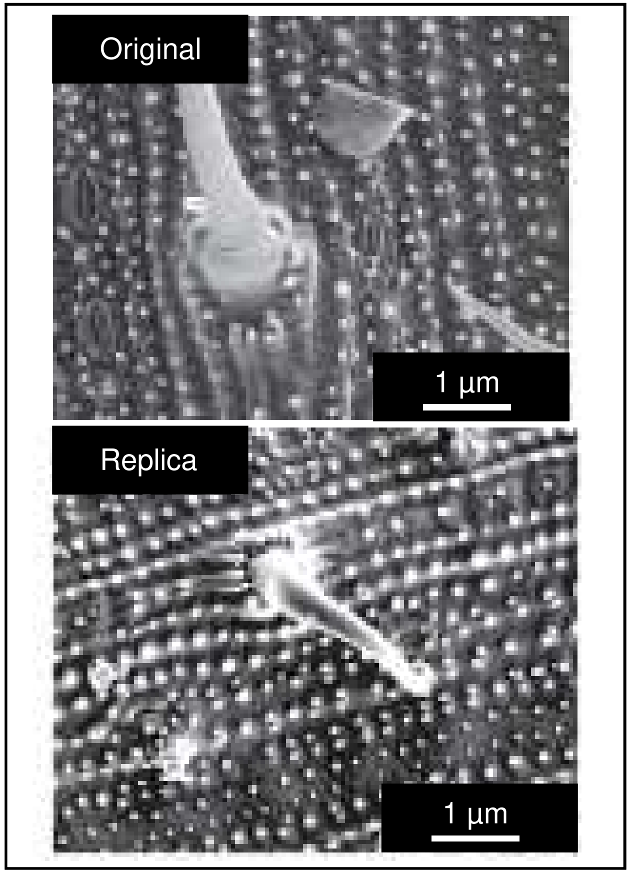
Electron beam lithography (2015)



"Nanofabrication and coloration study of artificial Morpho butterfly wings with aligned lamellae layers" Sichao Zhang & Yifang Chen, Scientific Reports volume 5, Article number: 16637 (2015)

Molding (2021)



« Mimicking the surface mechanical properties of rice (Oryzae sativa) leaf using PDMS soft lithography »Nicholas Bohlim, Donghee Lee, Sangjin Ryu & Richard A. Wilson JMST Advances volume 3, pages11–17 (2021)

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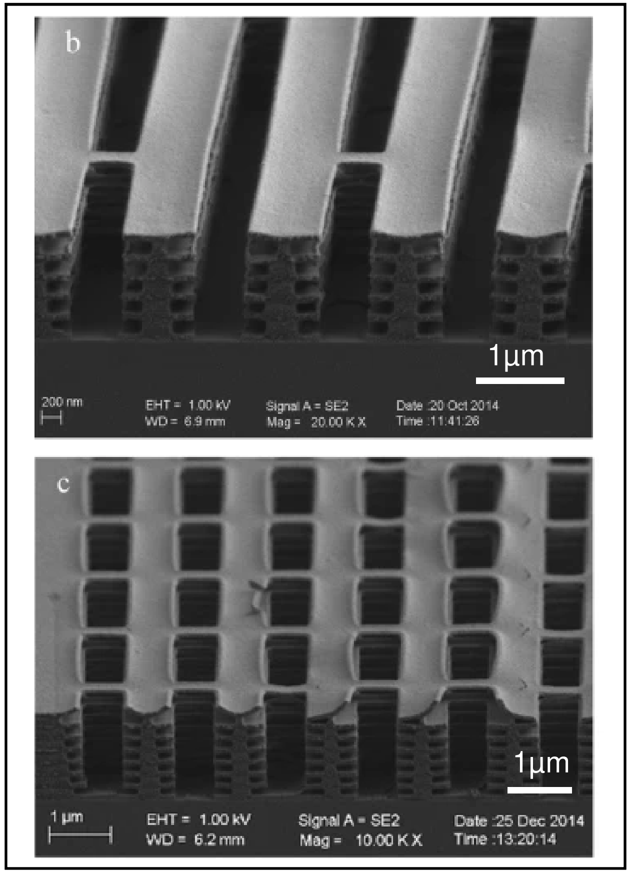
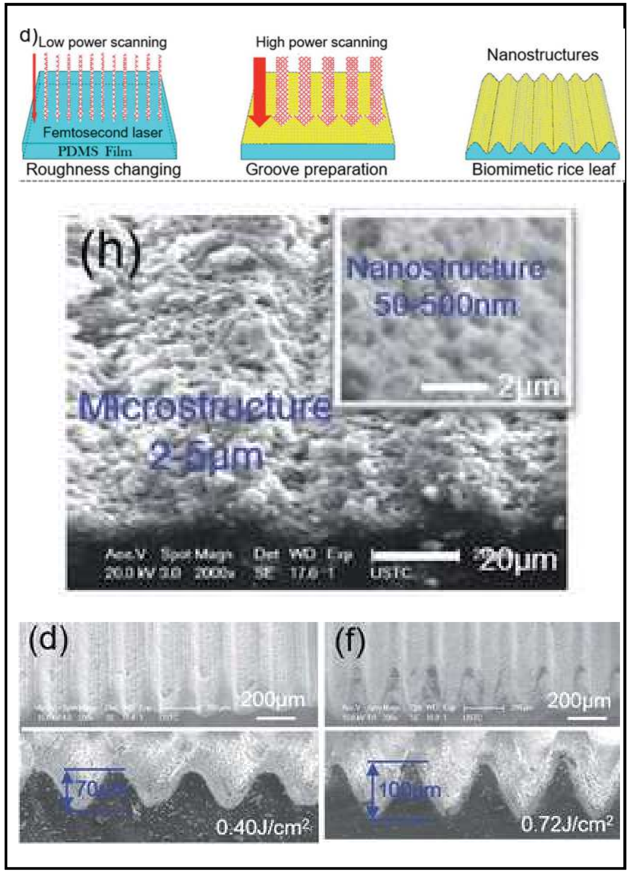


"Nanofabrication and coloration study of artificial Morpho butterfly wings with aligned lamellae layers" Sichao Zhang & Yifang Chen, Scientific Reports volume 5, Article number: 16637 (2015)

Femtosecond laser (2017)



« Biomimetic surfaces with anisotropic sliding wetting by energy-modulation femtosecond laser irradiation for enhanced water collection »Yang Lu et al. (2017) Materials Science RSC Advances

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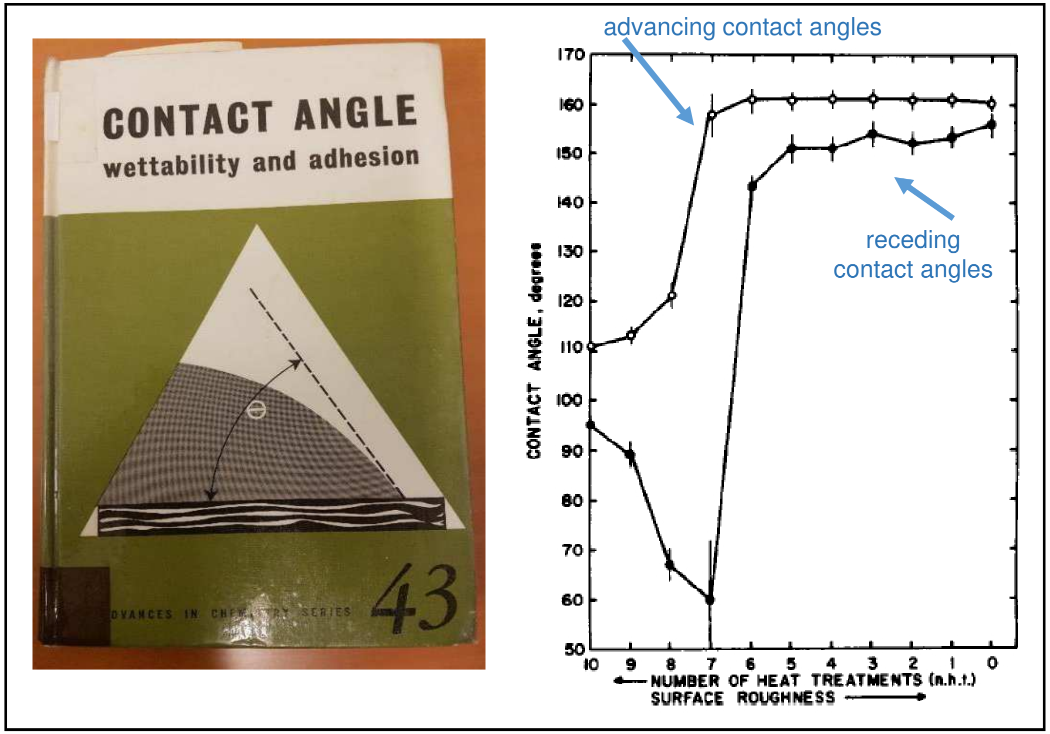
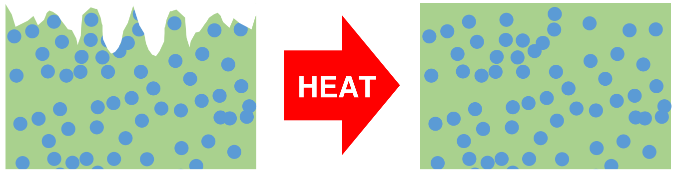
Dettre and Johnson (1964)



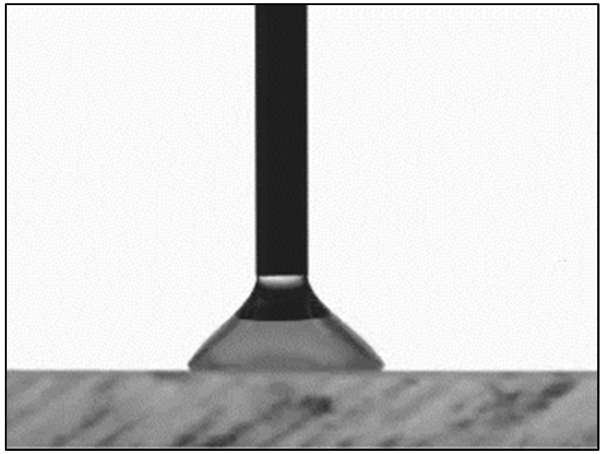
II. Contact Angle Measurements on Rough Surfaces R. H. DETTRE and R. E. JOHNSON JR.
Contact Angle, Wettability, and Adhesion, Editor(s): Frederick M. Fowkes Volume 43
Chapter 8, pp 136-144 **DOI:** 10.1021/ba-1964-0043.ch008

Wax + glass beads



rough smooth

➡ Advancing and receding contact angles



"Gouttes, bulles, perles et ondes" Pierre-Gilles de Gennes, Françoise Brochard-Wyart, David Quéré (Éditions Belin)

Superhydrophobic state is characterized by a high contact angle AND low contact angle hysteresis

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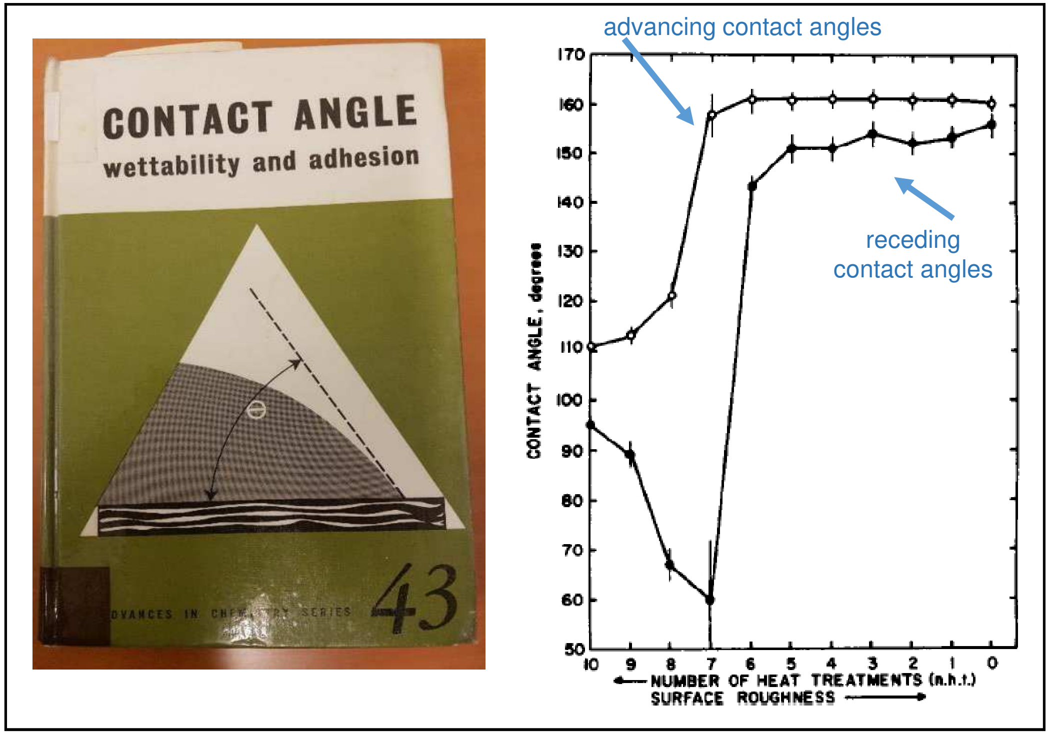

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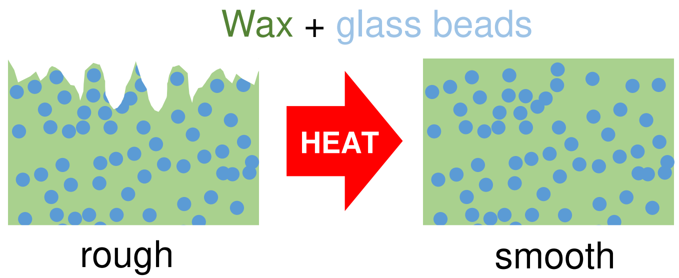

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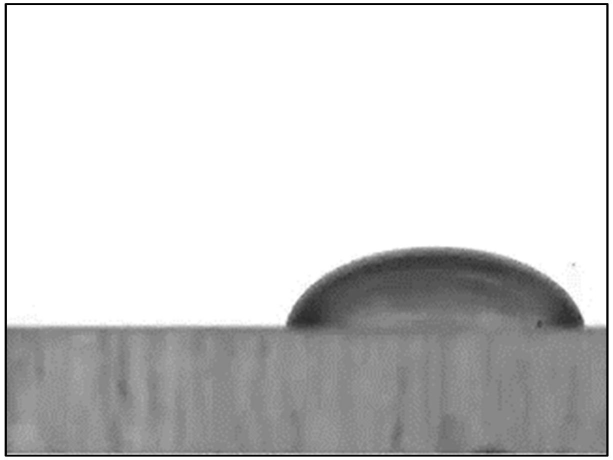

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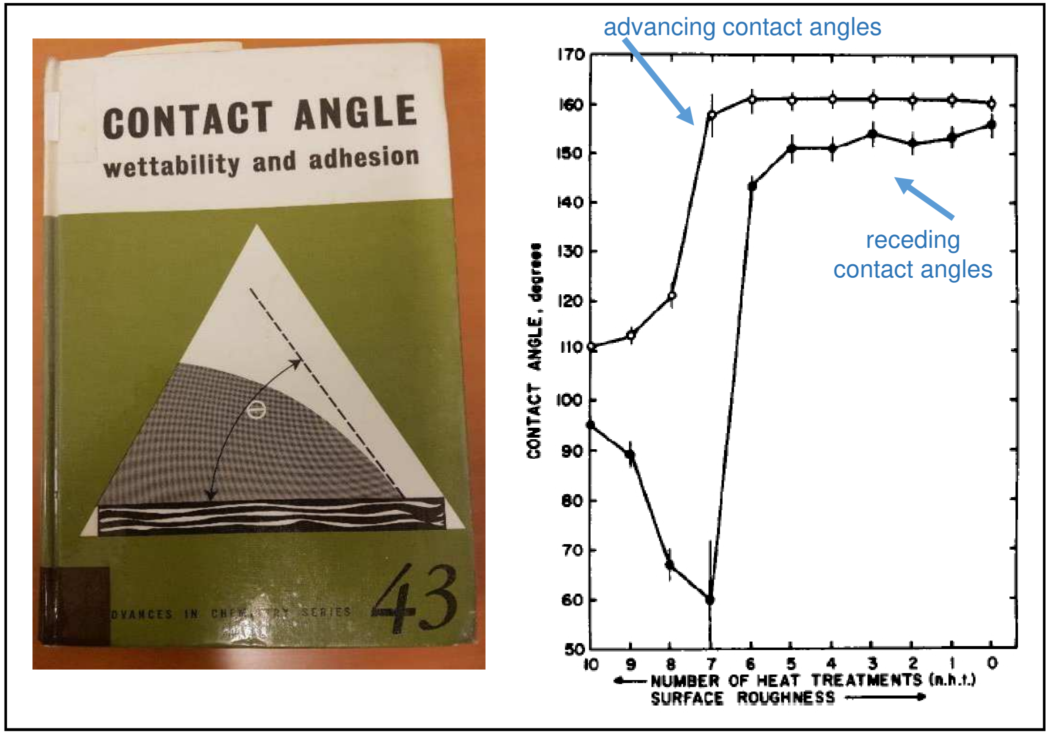

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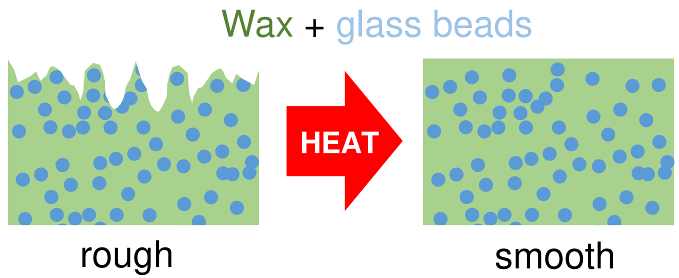

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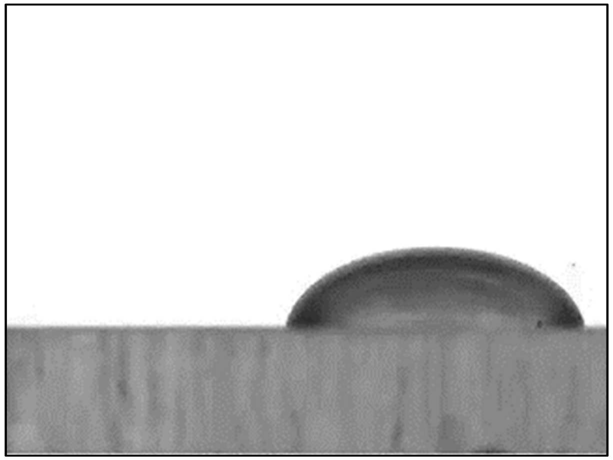

$\theta a - \theta r$ = **hysteresis**

Hysteresis = adhesion

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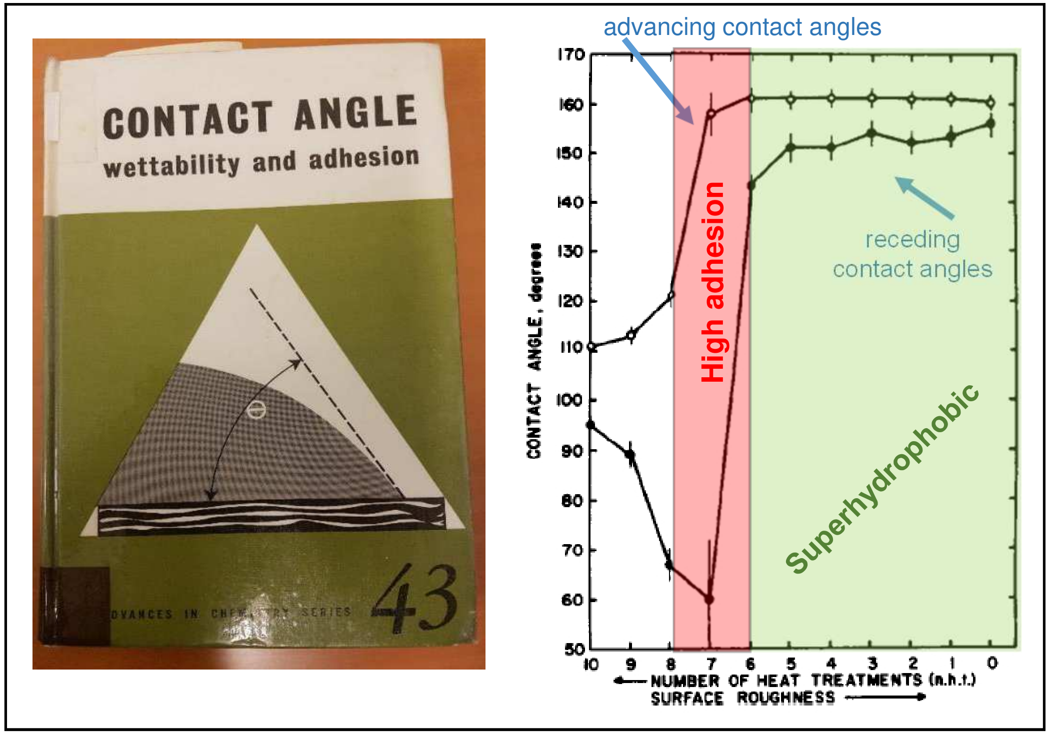

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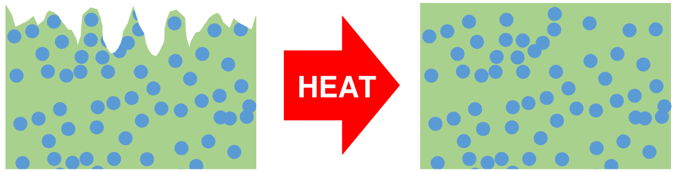

rough smooth

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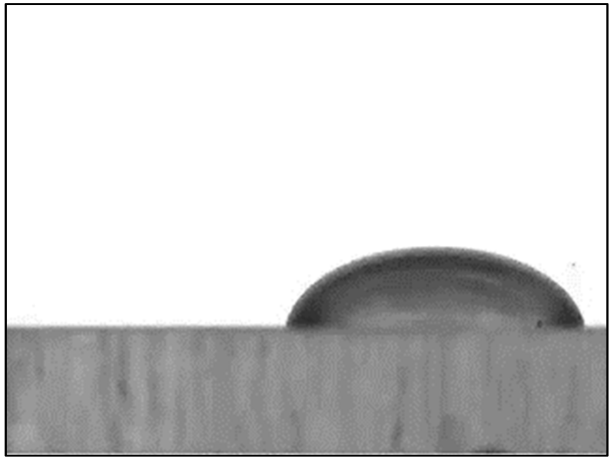

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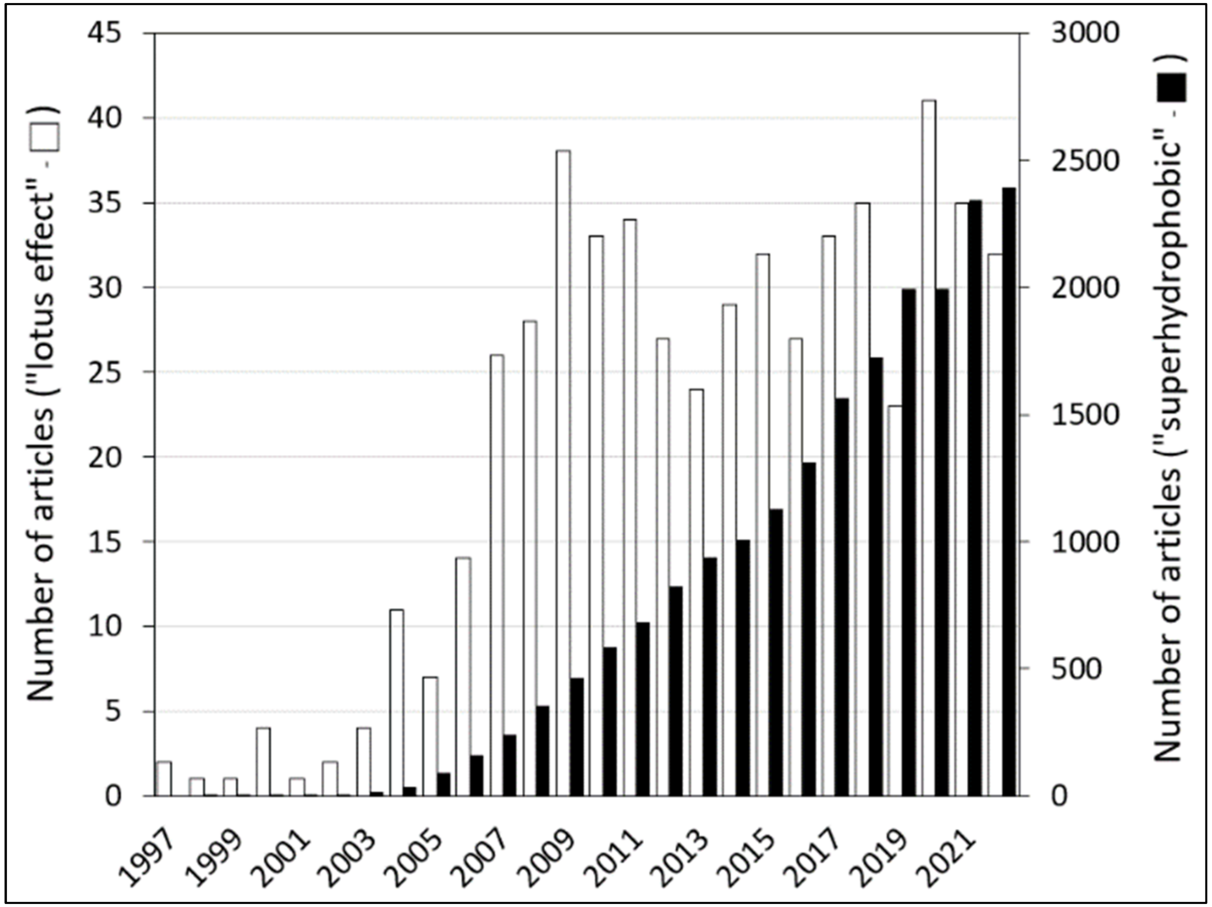
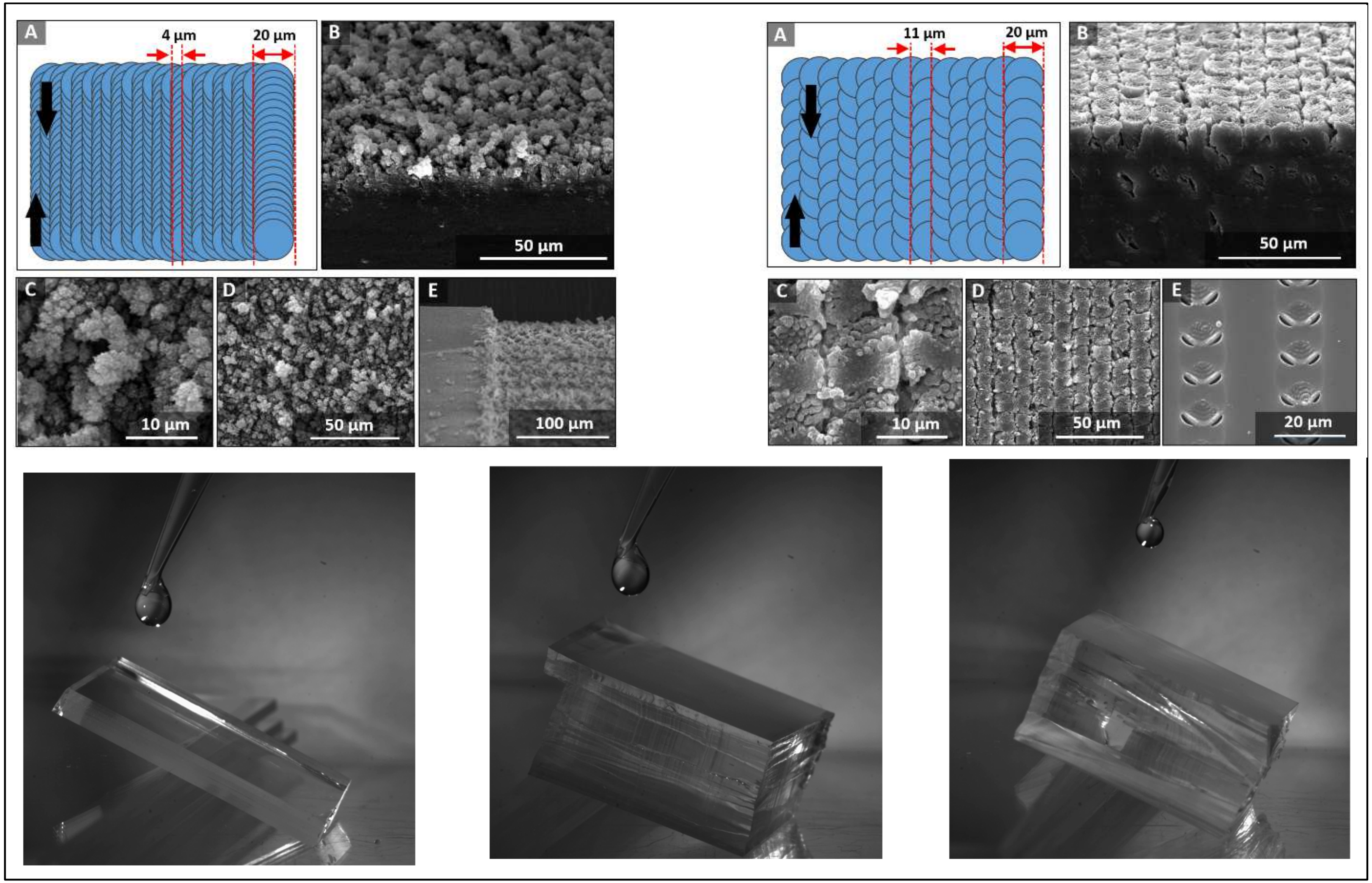


Occurrence of the terms "lotus effect" and "superhydrophobic" since 1997 according to Web of science-Clarivate (for the search fields “Title”, “Abstract” and “Keywords”. Using this bibliographic tool, the term "superhydrophobic" already appeared 6 times before 1997 in the field of chemical engineering and cell science.

Surfaces not wetted by liquids even of low surface tension = sessile drop method is not suited anymore

3/ Wetting of textured surfaces

- **Advanced techniques for characterizing the wetting… of non-wetting surfaces**



V Hisler, H Jendoubi, C Hairaye, L Vonna, V Le Houérou, F Mermet, M Nardin, H Haidara *Tensiometric Characterization of Superhydrophobic Surfaces As Compared to the Sessile and Bouncing Drop Methods*, Langmuir **32** (31) ,7765-7773 (2016)

4/ Resisting wetting

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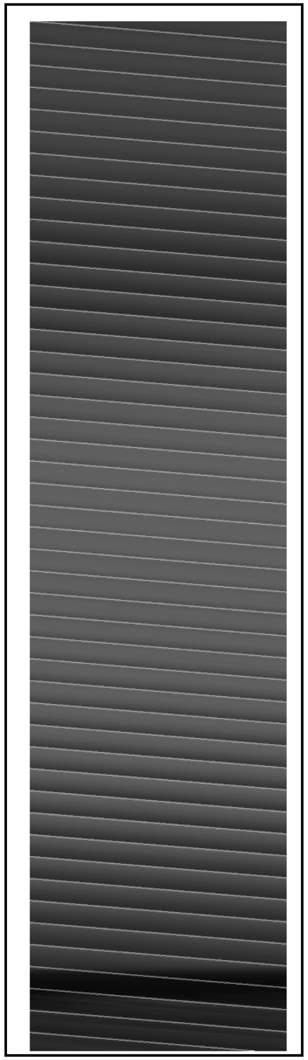

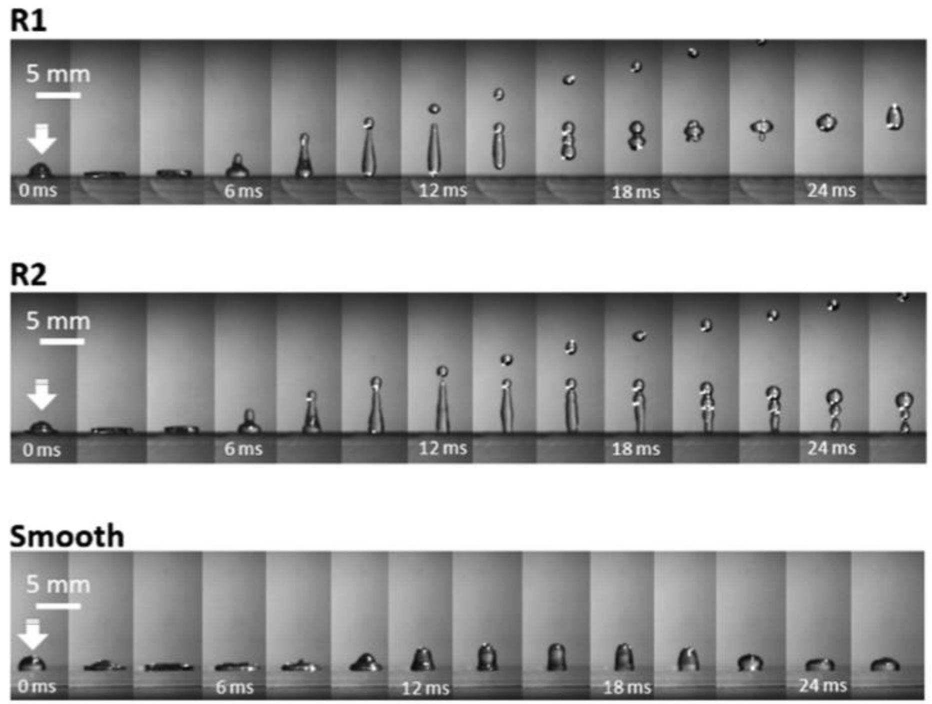

Figure 6. High-speed image sequences of water droplets hitting the two superhydrophobic PDMS surfaces (R1 and R2) and a smooth PDMS surface at an impact velocity of 1.1 ± 0.1 m·s^{-1} in the three cases (falling height of 5.5 cm).

V Hisler, H Jendoubi, C Hairaye, L Vonna, V Le Houérou, F Mermet, M Nardin, H Haidara *Tensiometric Characterization of Superhydrophobic Surfaces As Compared to the Sessile and Bouncing Drop Methods*, Langmuir **32** (31) ,7765-7773 (2016)

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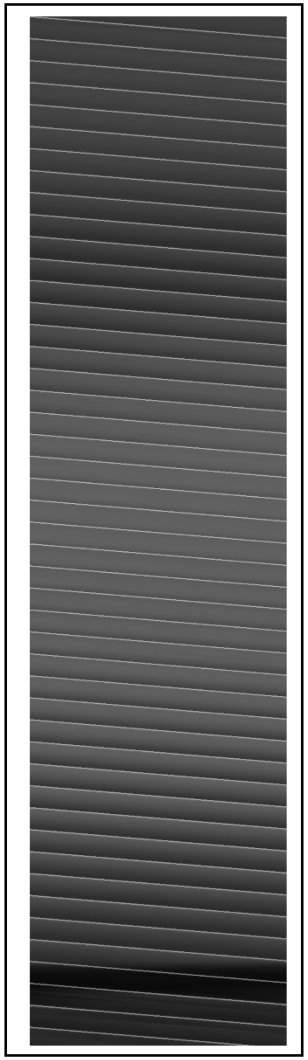

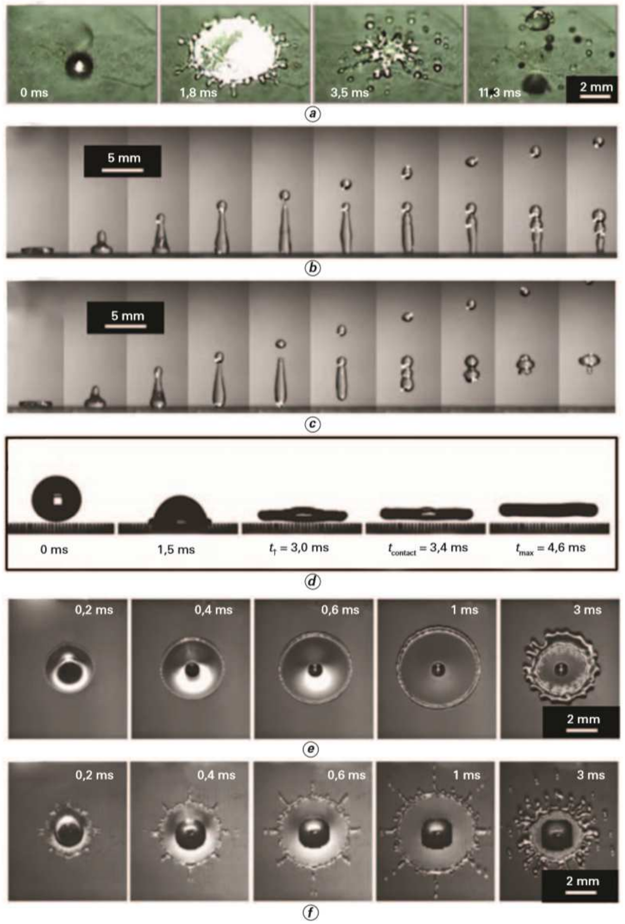

(a) séquence de l'impact d'une goutte d'eau sur une feuille de chou *Brassica oleracea L.*
(b) (c) rebond d'une goutte d'eau sur une surface superhydrophobe, avec, et sans ancrage respectivement
(d) rebond de goutte en mode *pancake*
(e) (f) vues de dessus de la fragmentation d'une goutte d'eau sur des surfaces décorées par des microplots séparés par une distance de 7,3 et 13,4 µm respectivement

The falling drop

Inertia to force wetting

SONG (M.), JU (J.) et LUO (S.), et al.– Controlling liquid splash on superhydrophobic surfaces by a vesicle surfactant. Sci Adv 3 : 1-8. doi: 10.1126/sciadv.1602188 (2017).

LIU (Y.), MOEVIUS (L.) et XU (X.), et al.–Pancake bouncing on superhydrophobic surfaces. Nat Phys 10 : 515-519. doi: 10.1038/ NPHYS2980 (2014).

TSAI (P.), HENDRIX (M.H.W.) et DIJKSTRA (R.R.M.), et al.–Microscopic structure influencing macroscopic splash at high Weber number. Soft Matter 7 : 11325. doi: 10.1039/ c1sm05801k (2011).

4/ Resisting wetting

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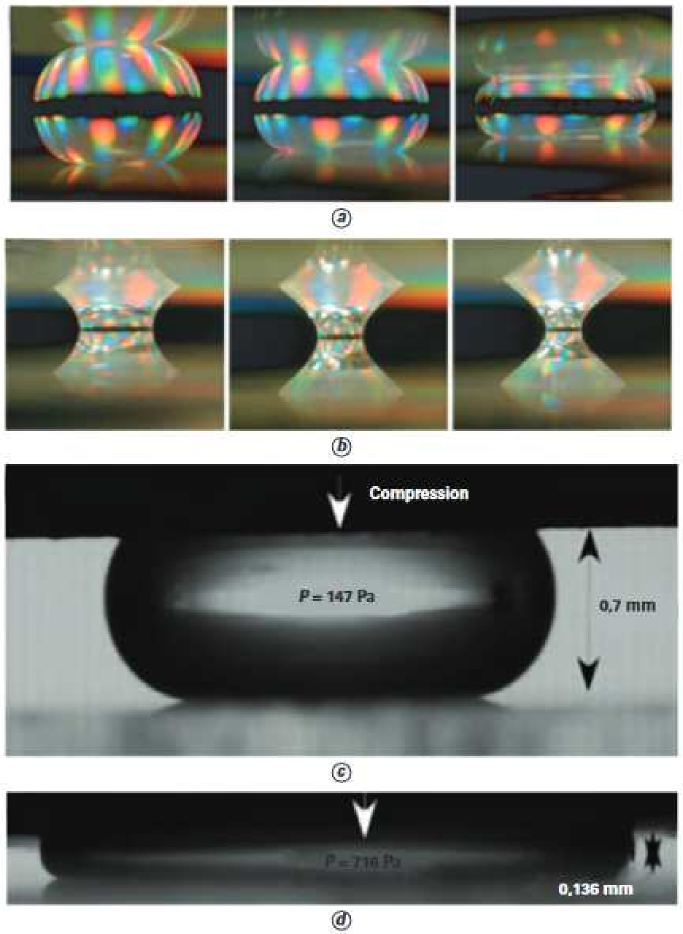


ⓐ ⓑ photographie d'une goutte d'eau compressée entre deux plaques superhydrophobes, puis lors de l'écartement des surfaces après transition de mouillage
ⓒ ⓓ compression extrême d'une goutte d'eau contre une surface de PMMA superomniphobe

The squeezed droplet

⬇

Critical pressure to induced the forced wetting

Lafuma A. and Quéré D.
Superhydrophobic states. Nat Mater 2 : 457-60. doi:10.1038/nmat924 (2003)

Gnanappa A.K., Papageirgiu D.P. and Gogolides E.et al.
Hierarchical, plasma nanotextured, robust superamphiphobic polymeric surfaces structurally stabilized through a wetting-drying cycle. Plasma Process Polym 9 : 304-315. doi: 10.1002/ppap.201100124 (2012)

Wettability
Laurent Vonna

1/ Surface tension and cohesive forces

2/ Wetting for a measure of the surface energy

3/ Wetting of textured surfaces

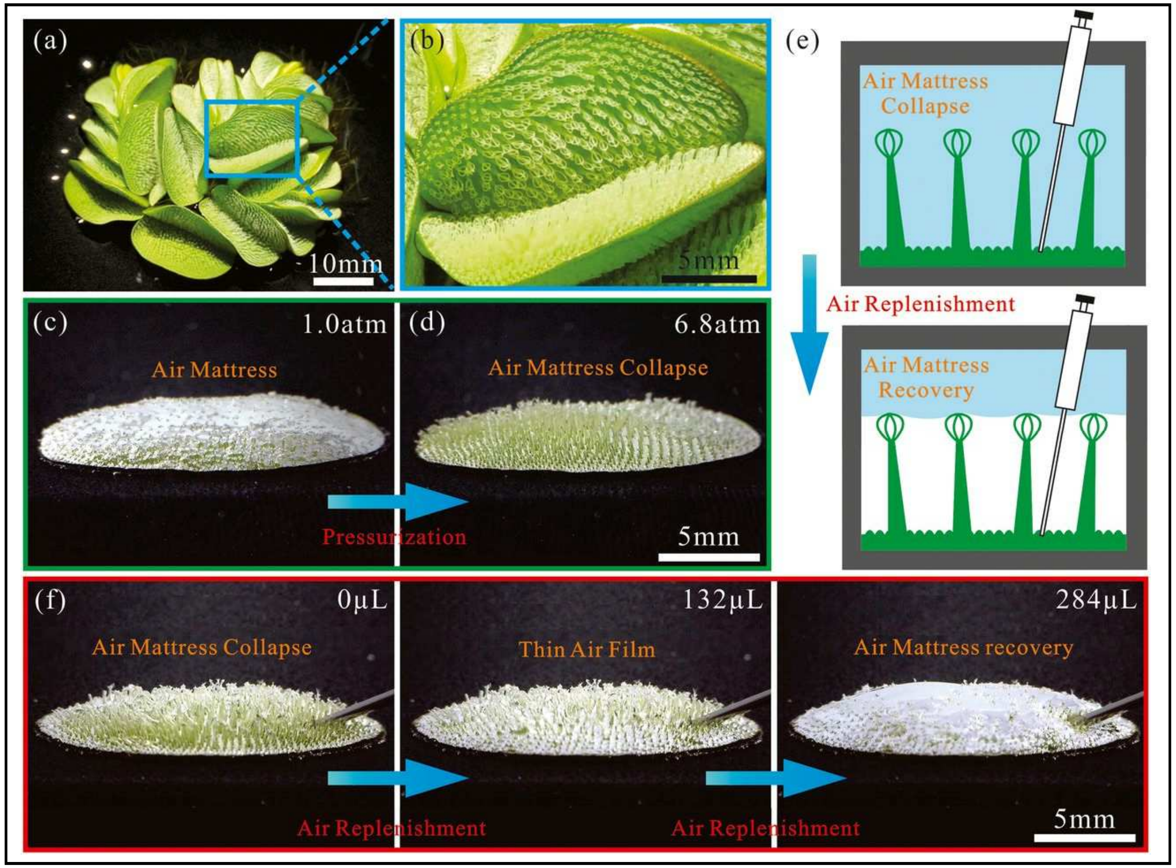
4/ Resisting wetting

5/ Liquid-infused surfaces

« Stability of the volume of air trapped on the abdomen of the water spider *Argyroneta aquatica* » Dietrich Neumann and Dietrich Woermann, Springerplus. 2013; 2: 694 doi: 10.1186/2193-1801-2-694

4/ Resisting wetting

- **Stability of an air layer at the surface of immersed *Salvinia molesta* leaves**



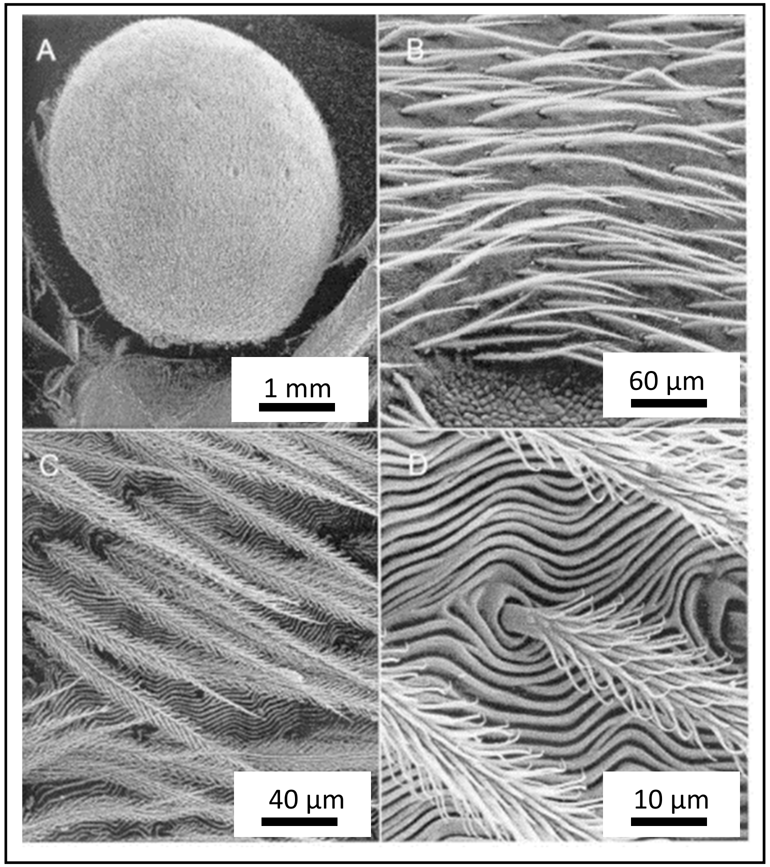
« Superrepellency of underwater hierarchical structures on Salvinia leaf »
Yaolei Xiang et al. Proc Natl Acad Sci U S A 2020 Feb 4;117(5):2282-2287. DOI: 10.1073/pnas.1900015117

➡ Stable air mattress
➡ = plastron

➡ Resist biofouling
➡ Resist bacterial adhesion
➡ Reduce drag

4/ Resisting wetting

- **The water spider *Argyroneta aquatica***



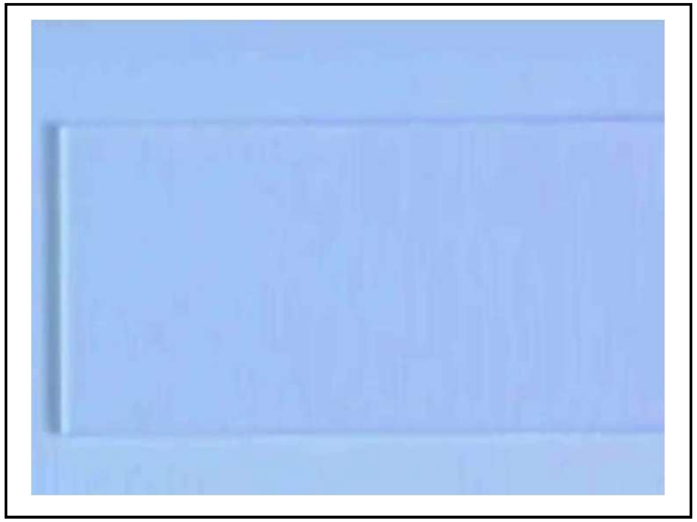
➡ Stable air mattress

➡ Stabilized by an abdomen covered with hairs

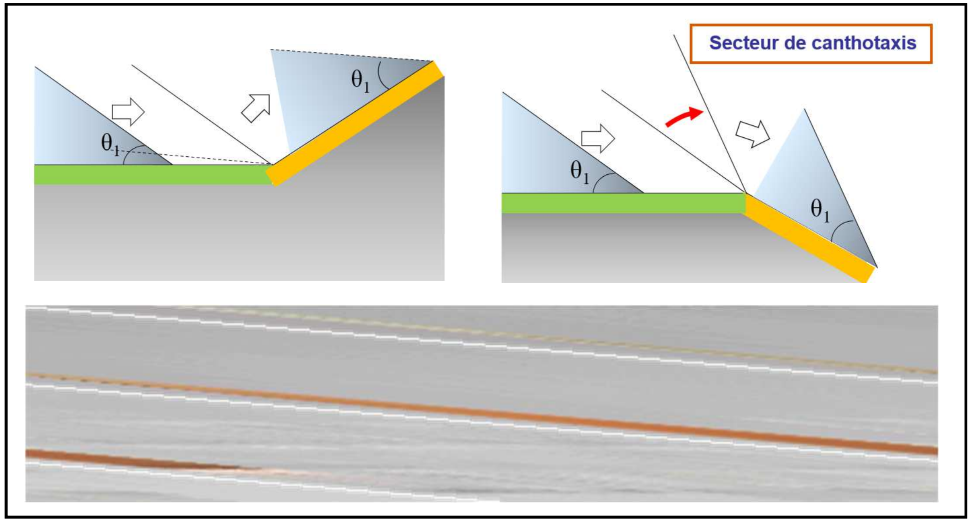
« Stability of the volume of air trapped on the abdomen of the water spider *Argyroneta aquatica* » Dietrich Neumann and Dietrich Woermann, Springerplus. 2013; 2: 694 doi: 10.1186/2193-1801-2-694

4/ Resisting wetting

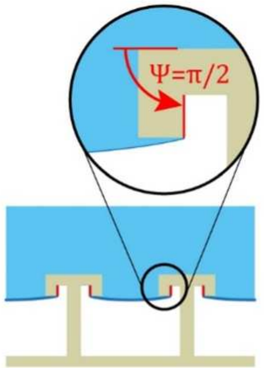
- **Pinning of the moving contact line using re-reentrant morphologies**



“Free-Running Droplets” Fabrice Domingues Dos Santos and Thierry Ondarçuhu Phys. Rev. Lett. 75, 2972 – Published 16 October 1995



“Gouttes, bulles, perles et ondes” Pierre-Gilles de Gennes, Françoise Brochard-Wyart, David Quéré (Éditions Belin)



➡ Re-entrant textures at the microscopic scale

➡ Resist wetting even with liquids of low surface tension

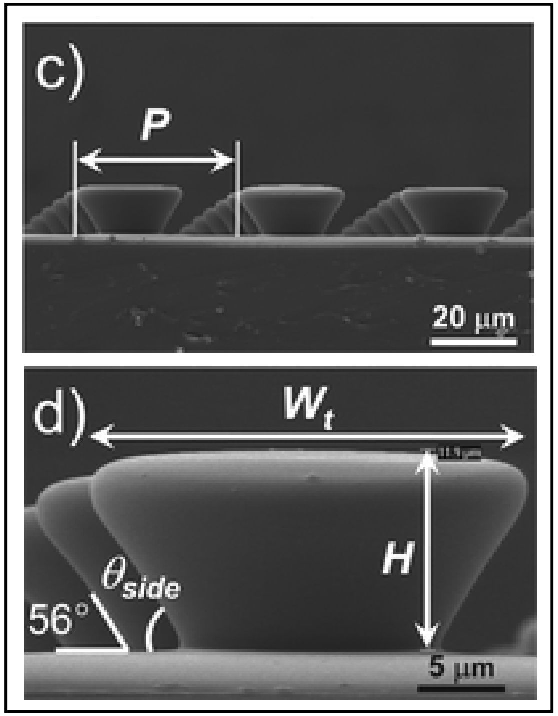
➡ Superoleophobic surfaces

« Why re-entrant surface topography is needed for robust oleophobicity » Michael Nosonovsky, B. Bhushan, 2016, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences DOI:10.1098/rsta.2016.0185

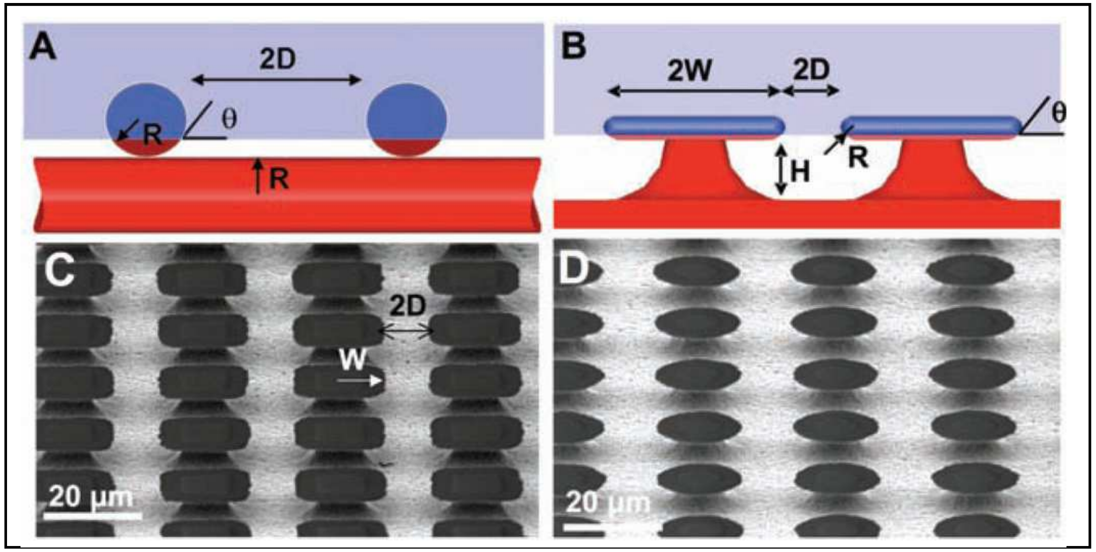
4/ Resisting wetting

- **Pinning of the moving contact line using re-reentrant morphologies**

Artificial re-entrant surface textures



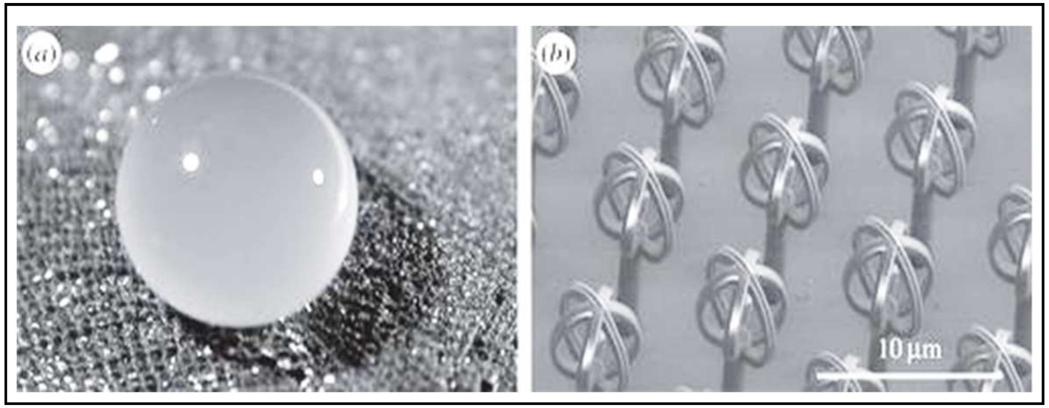
« A robust superhydrophobic and superoleophobic surface with inverse-trapezoidal microstructures on a large transparent flexible substrate » Maesoon Im, Hown Im, Joo-Hyung Lee, Jun-Bo Yoon and Yang-Kyu Choi ***Soft Matter***, 2010,**6**, 1401-1404



« Design parameters for superhydrophobicity and superoleophobicity ». Tuteja, A.; Choi, W.; McKinley, G.H.; Cohen, R.E.; Rubner, M.F. MRS Bull. 2008, 33, 752–758.

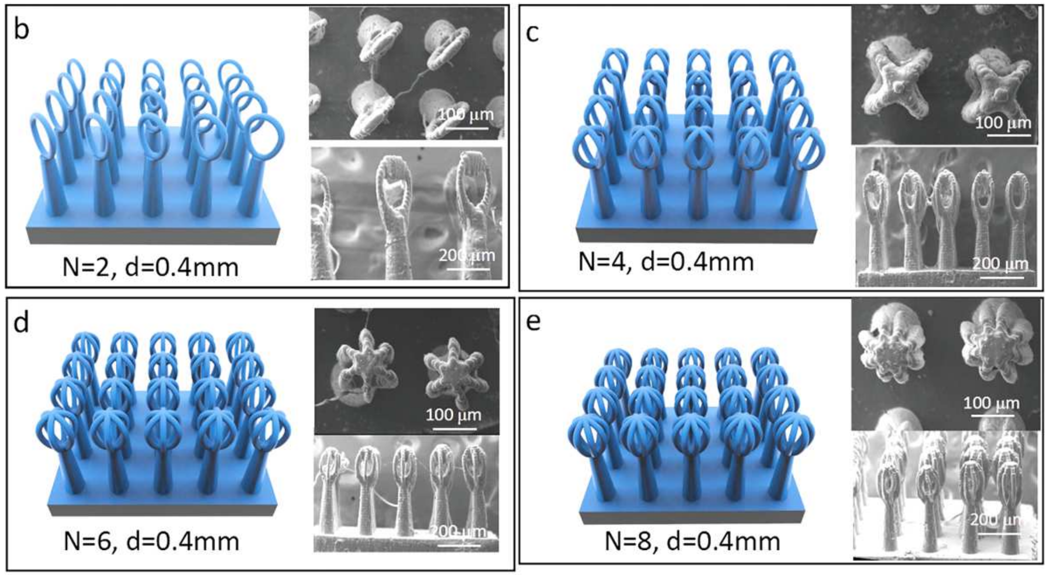
The rose petal effect

3D printed salvinia-like microtextures (2015)



Tricinci O, Terencio T, Mazzolai B, Pugno NM, Greco F, Mattoli V. « 3D micropatterned surfaces inspired by *Salvinia molesta* via direct laser lithography ». (2015) **ACS Appl. Mater. Interfaces 7**, 25 560–25 567. (doi:10.1021/acsami.5b07722)

(2018)



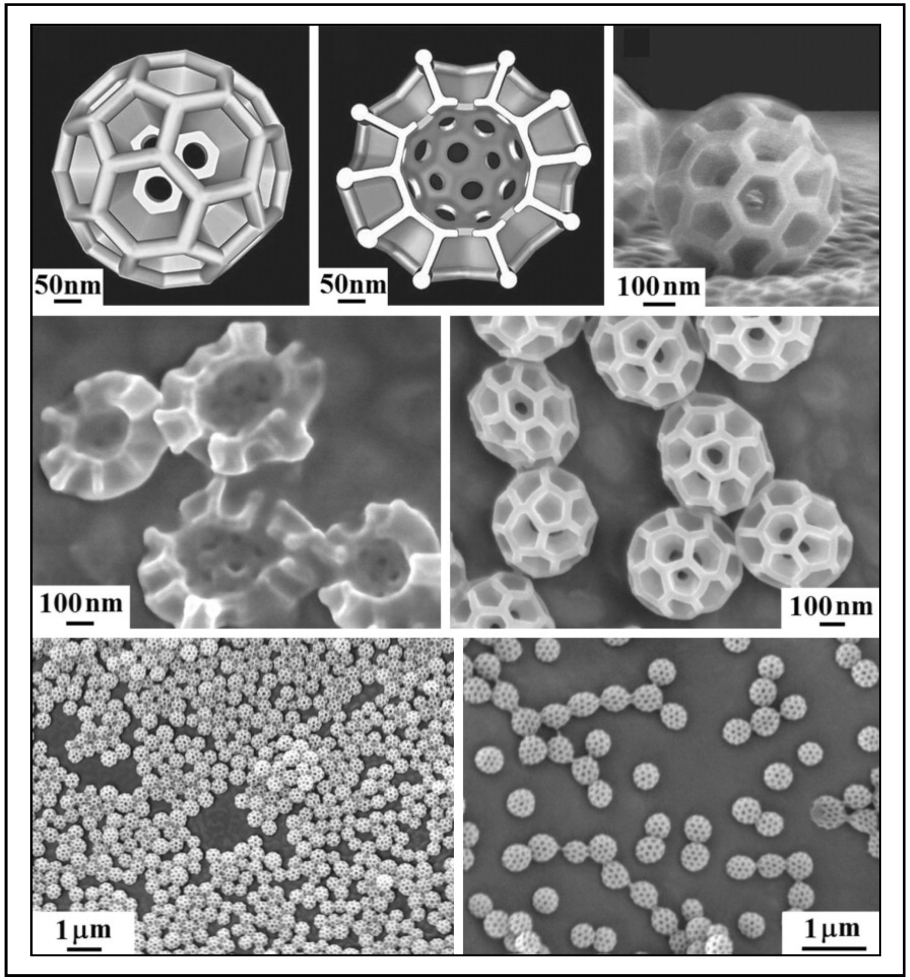
« 3D-Printed Biomimetic Super-Hydrophobic Structure for Microdroplet Manipulation and Oil/Water Separation » Yang Yang, Xiangjia Li, Xuan Zheng, Zeyu Chen, Qifa Zhou, Yong Chen less 2018 Materials Science, Engineering Advanced Materials

4/ Resisting wetting

- **Pinning of the moving contact line using re-reentrant morphologies**

Re-entrant surface textures in nature

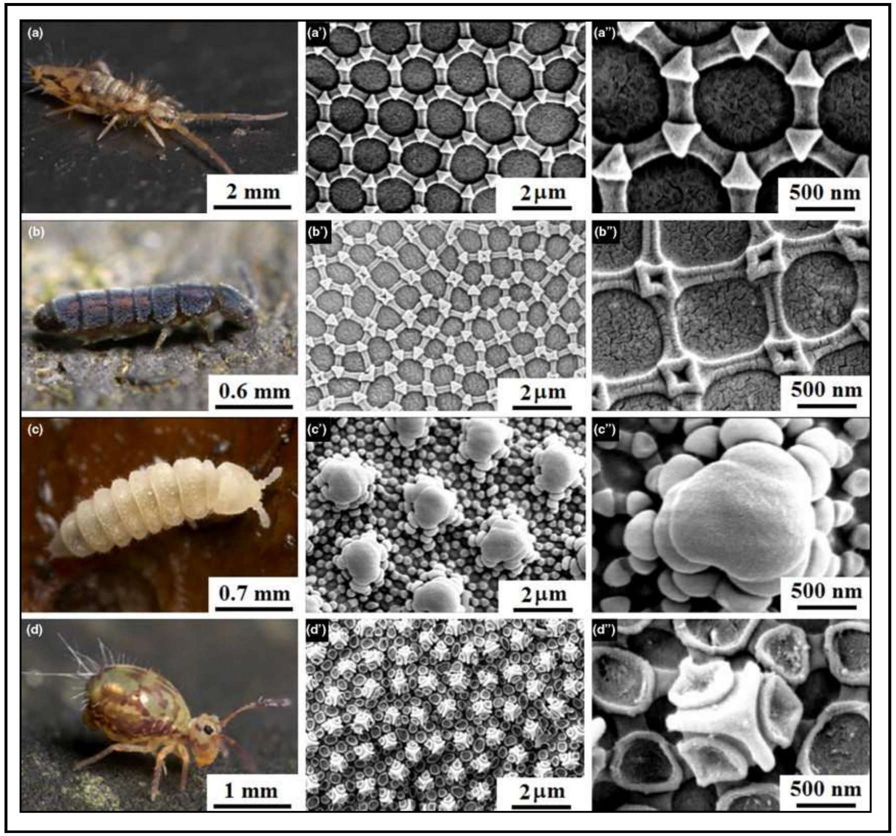
« Brochosomal coats turn leafhopper (Insecta, Hemiptera, Cicadellidae) integument to superhydrophobic state » Roman Rakitov, Stanislav N. Gorb Proceedings of the Royal Society B 80: 20122391 (2013)



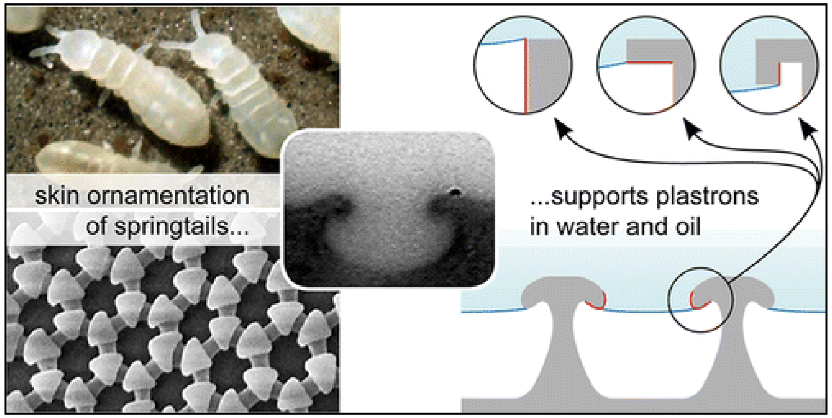
4/ Resisting wetting

- **Pinning of the moving contact line using re-reentrant morphologies**

Re-entrant surface textures in nature



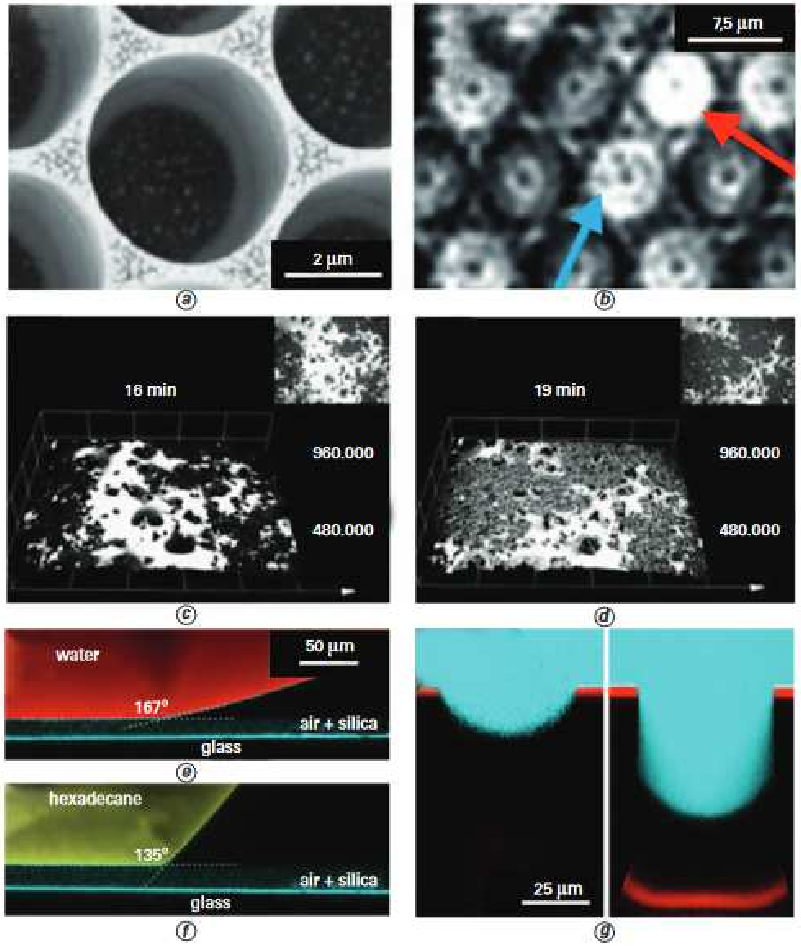
J. Nickerl, et al. Zoomorphology, 132 (2) (2013), p. 183



« Wetting Resistance at Its Topographical Limit: The Benefit of Mushroom and Serif T Structures »
René Hensel, Ralf Helbig, Sebastian Aland, Hans-Georg Braun, Axel Voigt, Christoph Neinhuis, and Carsten Werner Langmuir, 2013, 29 (4), pp 1100–1112

4/ Resisting wetting

- **Advanced techniques for characterizing the wetting… of non-wetting surfaces**



ⓐ image de microscopie électronique à balayage des surfaces microtexturées utilisées par Søgaard *et al.*
ⓑ image de microscopie optique des trois états de remplissage des microcavités avec en rouge un remplissage de type Wenzel, en bleu un état suspendu (Cassie-Baxter), le reste étant dans un régime mixte
ⓒ ⓓ évolution d'un film d'air confiné lors d'une transition d'un régime de Cassie-Baxter vers un régime de Wenzel
ⓔ ⓕ images de microscopie confocale d'un lit de billes de silice sous une goutte d'eau et d'huile respectivement
ⓖ images de microscopie confocale de l'avancée d'un front de mouillage dans une microcavité

Optical techniques

⬇

For the stability and the morphology of the air cushion

Sogaard, E. et al. Study of Transitions between Wetting States on Micro-cavity Arrays by Optical Transmission Microscopy. Langmuir 30 : 12960-12968. doi: DOI: 10.1021/la502855g (2014).

Lei, L.I., Shi, J., and Cheny, Y.Diffraction patterns of a water-submerged superhydrophobic grating under pressure. Langmuir 26 :3666-3669 doi:10.1021/la903150h (2010).

Luo, C. et al. – Direct three-dimensional imaging of the buried interfaces between water and superhydrophobic surfaces AngewChemie–IntEd 49 :9145148 doi:10.1002/anie.201002470 (2010).

Papadopoulos, P. et al. Electrokinetics on superhydrophobic surfaces. JPhysCondens Matter24:464110 doi:10.1088/0953-8984/ 24/46/464110 (2012).

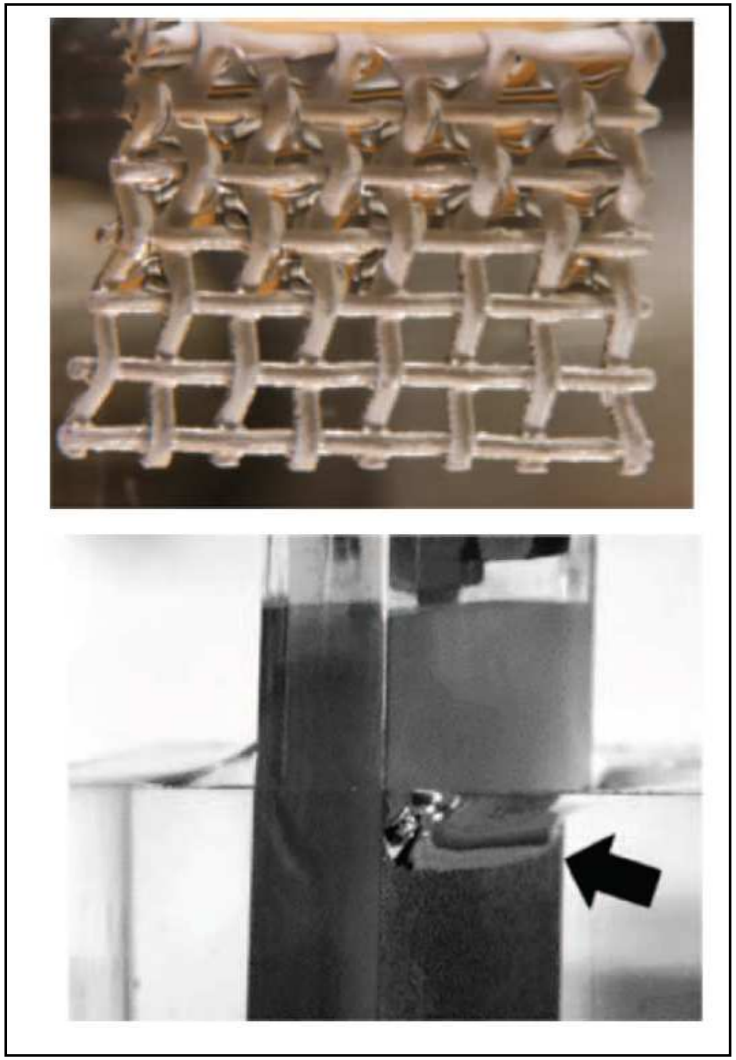
Lu, P. et al. – Metastable states and wetting transition of submerged superhydrophobic structures. PhysRevLett 112:1-5 doi:10.1103/PhysRevLett.112.196101 (2014).

⬇

What is the ability of a surface to resist wetting (hydrostatic pressure, biological conditions,…)

4/ Resisting wetting

- **Advanced techniques for characterizing the wetting… of non-wetting surfaces**



Wilhlemy plate

Adhesion under immersion

Kleingartner, J.A. et al. Utilizing Dynamic Tensiometry to Quantify Contact Angle Hysteresis and Wetting State Transitions on Nonwetting Surfaces. Langmuir 29 : 13396-13406 doi: DOI: 10.1021/la4022678 (2013).

Kim, J.-H. et al. Dynamic contact angle measurements on superhydrophobic surfaces. Phys Fluids
27 : 032107
doi: 10.1063/1.4915112 (2015).

V Hisler, H Jendoubi, C Hairaye, L Vonna, V Le Houérou, F Mermet, M Nardin, H Haidara Tensiometric Characterization of Superhydrophobic Surfaces As Compared to the Sessile and Bouncing Drop Methods, Langmuir 32 (31) ,7765-7773 (2016)

What is the ability of a surface to resist wetting (hydrostatic pressure, biological conditions,…)

Wettability
Laurent Vonna

1/ Surface tension and cohesive forces

2/ Wetting for a measure of the surface energy

3/ Wetting of textured surfaces

4/ Resisting wetting

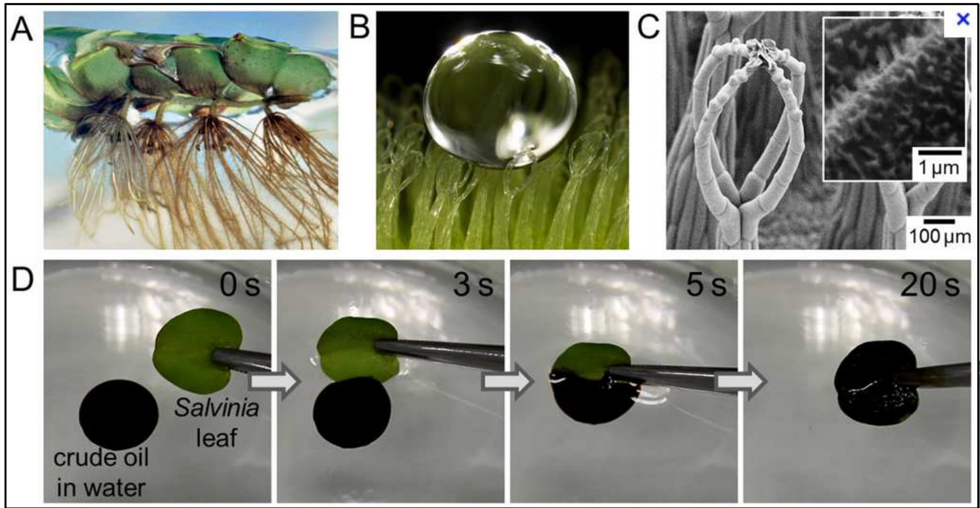
5/ Liquid-infused surfaces

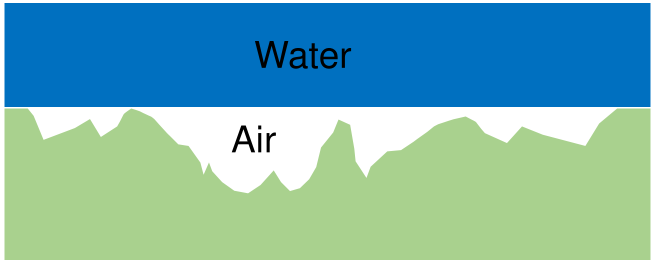
http://especes-exotiques-envahissantes.fr/espece/salvinia-molesta/

Journée thématique du GDR B2I, Paris, 12 octobre 2023
Techniques avancées de caractérisation de matière molle, biointerface ou biodispositif

5/ Liquid infused surfaces

- **Replacement of the plastron by oil**





➡ Liquid-infused surface

➡ Stable liquid layer

Microstructures of superhydrophobic plant leaves - inspiration for efficient oil spill cleanup materials Claudia Zeiger, Isabelle C Rodrigues da Silva, Matthias Mail, Maryna N Kavalenka, Wilhelm Barthlott and Hendrik Hölscher Bioinspiration & Biomimetics, Volume 11, Number 5

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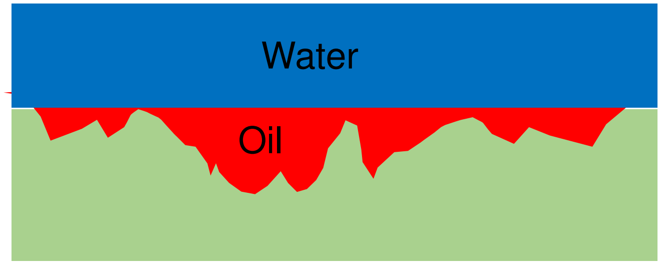

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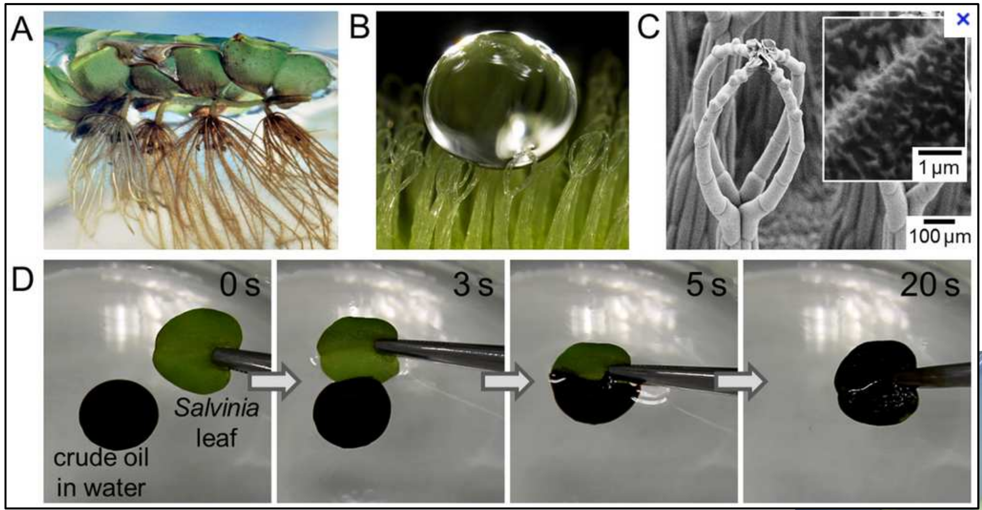

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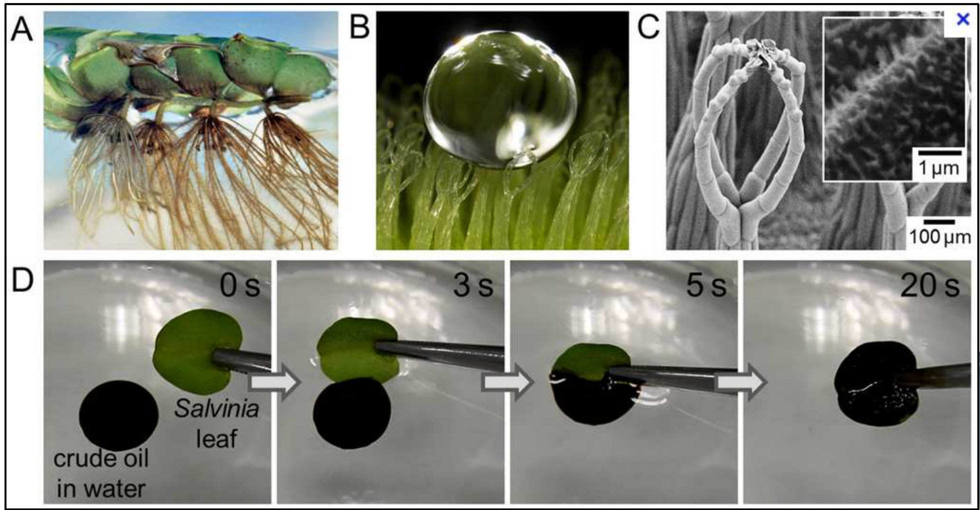

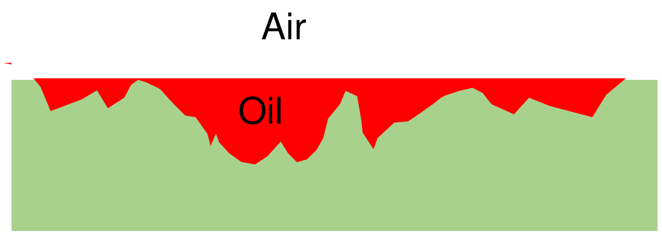

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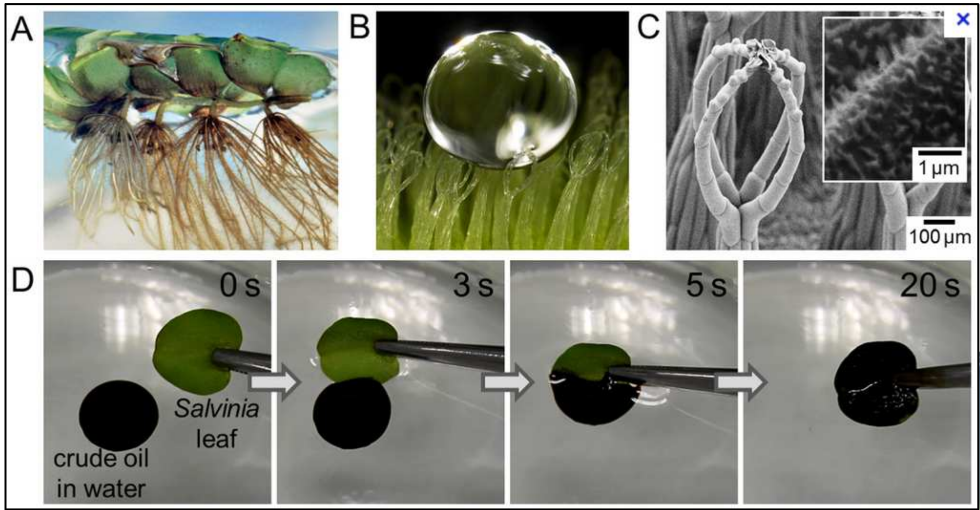

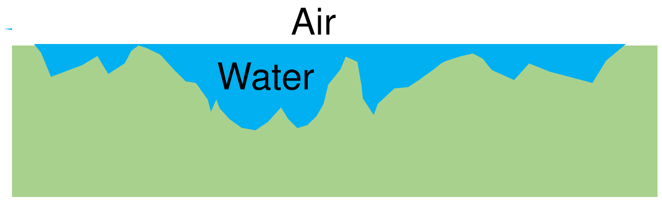

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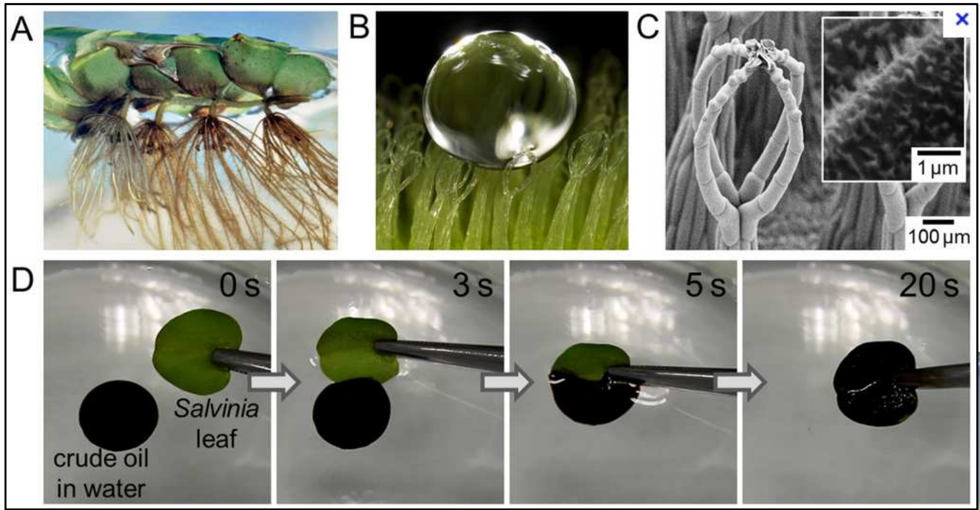

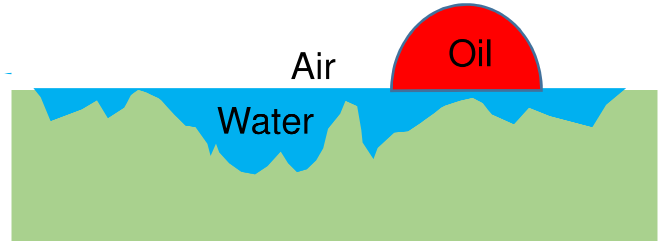

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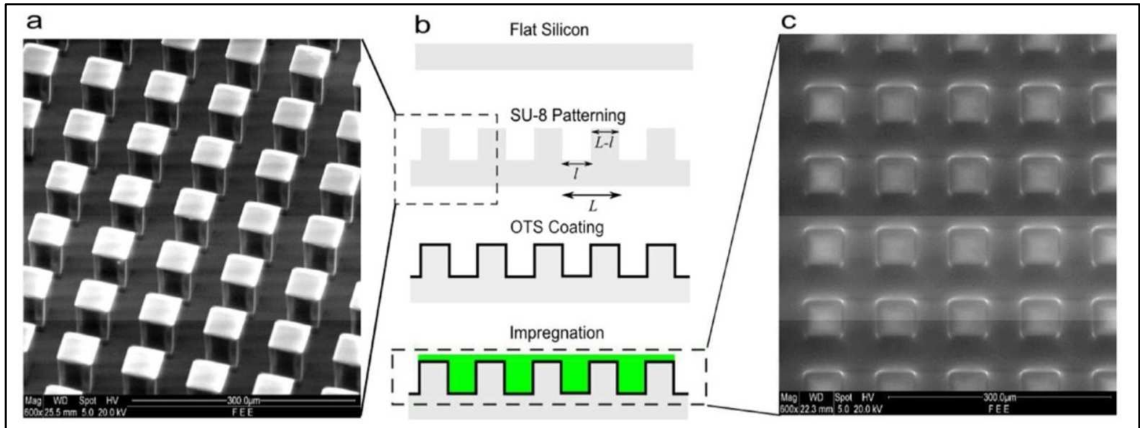
Lubricated surfaces



(a) Microtextured surface, (b) Schematic illustration of SLIPS surface, (c) SLIPS surface

« Droplet mobility on lubricant-impregnated surfaces » J. David Smith, Rajeev Dhiman, Sushant Anand, Ernesto Reza-Garduno, Robert E. Cohen, Gareth H. McKinley and Kripa K. Varanasi Soft Matter, 6, 2013

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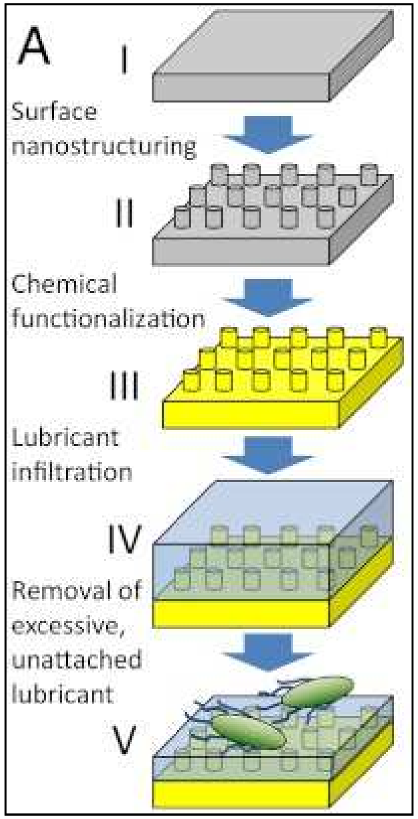


Anti-adhesive surfaces (against bacteria)

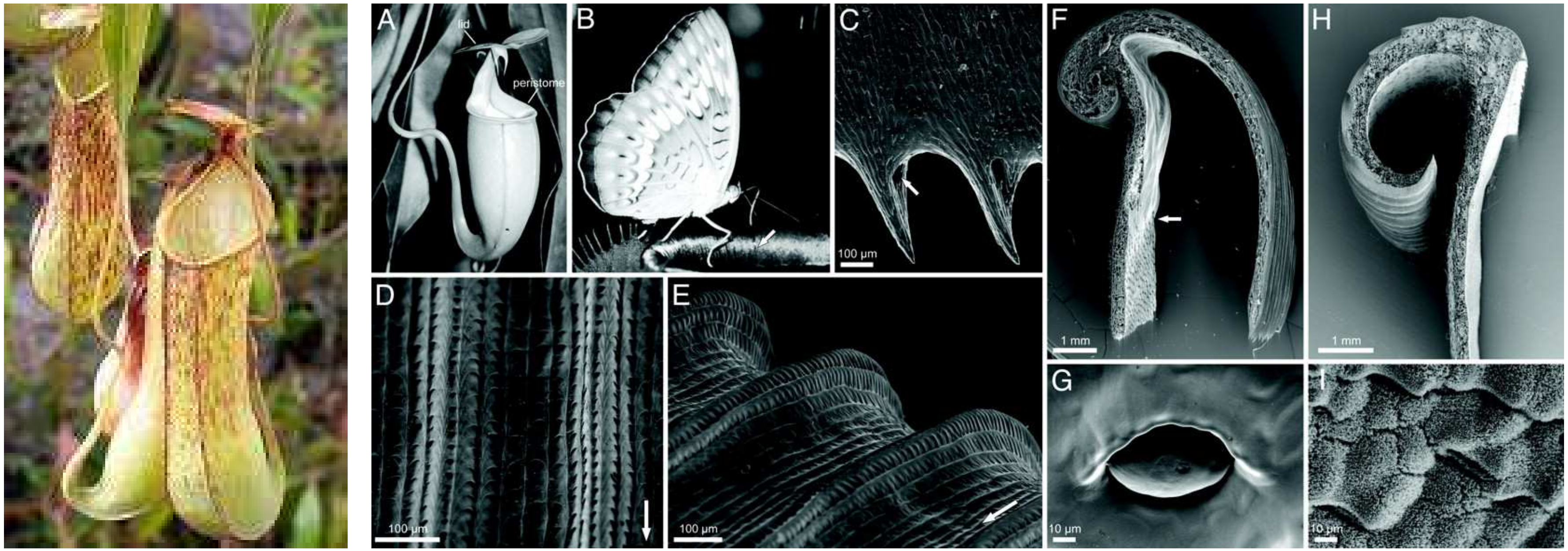
Slippery Liquid-Infused Porous Surfaces (SLIPS) prevent
- 99.6% of Pseudomonas aeruginosa biofilm attachment
- 97.2 % of Staphylococcus aureus biofilm attachment
- 96 % of Escherichia coli biofilm attachment

under both static and physiologically realistic flow conditions.

Proc Natl Acad Sci U S A. 2012 Aug 14;109(33):13182-7. doi: 10.1073/pnas.1201973109. Epub 2012 Jul 30 **Liquid-infused structured surfaces with exceptional anti-biofouling performance.** Epstein AK[1], Wong TS, Belisle RA, Boggs EM, Aizenberg J.

5/ Liquid infused surfaces

- **Nepenthes pitcher plants capture strategy**



« Insect aquaplaning: Nepenthes pitcher plants capture prey with the peristome, a fully wettable water-lubricated anisotropic surface »
Holger F Bohn and Walter Federle 2004 ,Sep 28;101(39):14138-43.
doi: 10.1073/pnas.0405885101

5/ Liquid infused surfaces

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5/ Liquid infused surfaces

- **Synthetic liquid infused surfaces**

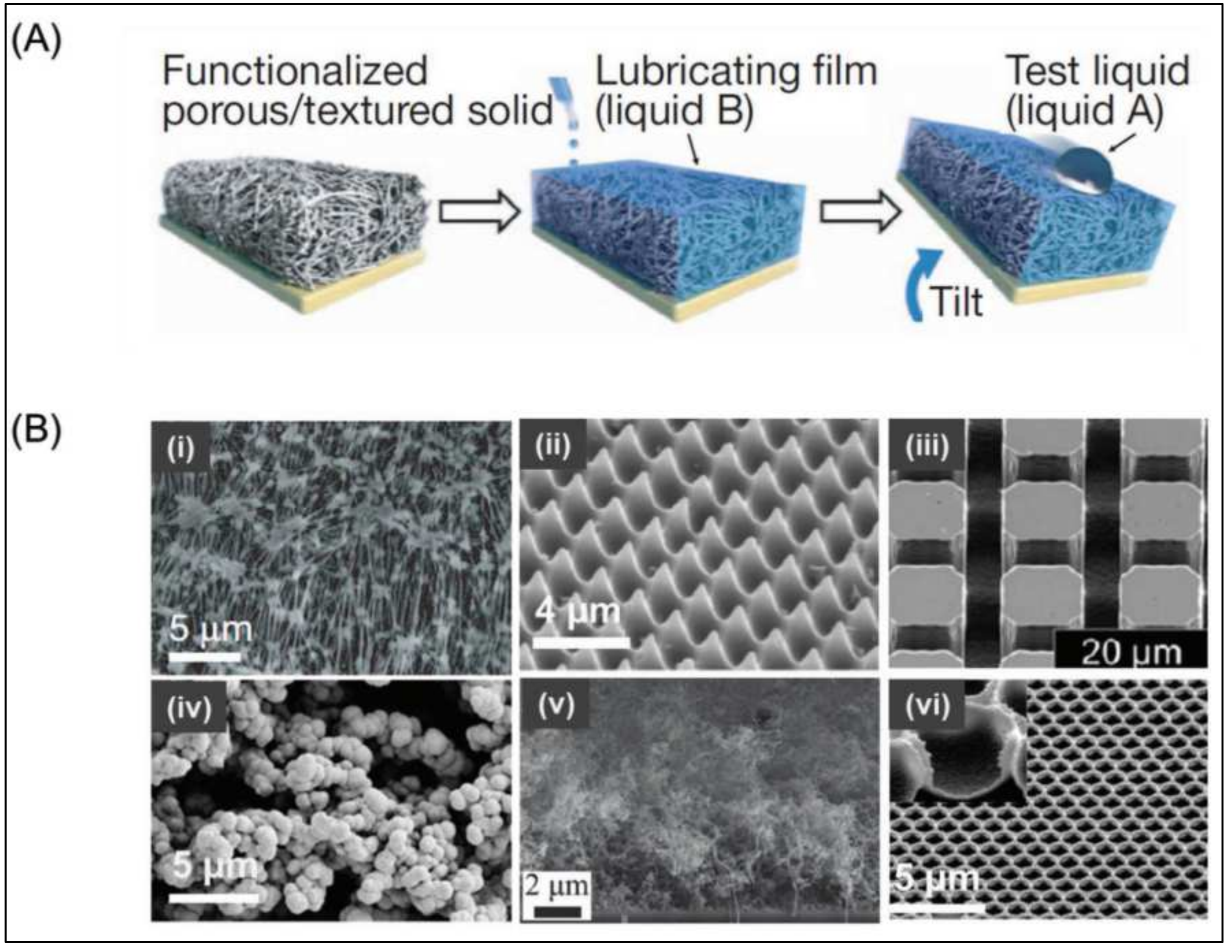


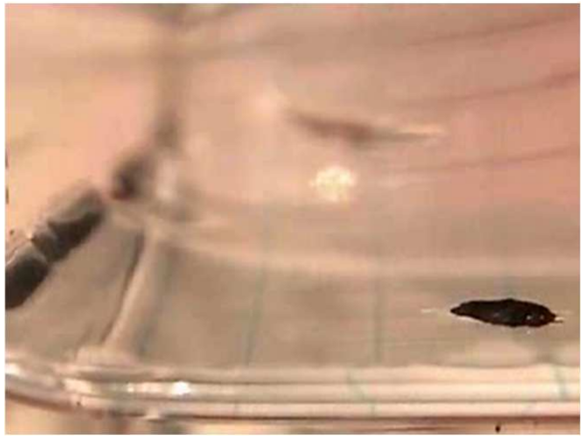
Figure 1. A) Scheme showing the fabrication of a lubricant-infused surface. Reproduced with permission.[9a] Copyright 2011, Springer Nature. B) SEM images of representative porous substrates used to fabricate SLIPS: (i) porous Teflon. Reproduced with permission.[9a] Copyright 2011, Springer Nature. (ii) Ordered polyacrylate. Reproduced with permission.[9a] Copyright 2011, Springer Nature. (iii) Silicon nanoarray. Reproduced with permission.[29] Copyright 2013, American Chemical Society. (iv) porous poly(butyl methacrylate-*co*-ethyleneglycol dimethacrylate). Reproduced with permission.[22] Copyright 2013, American Chemical Society. (v) porous silicone nanofilament, Reproduced with permission.[30] Copyright 2014, Wiley-VCH. (vi) inverse colloidal monolayer. Reproduced with permission.[28] Copyright 2013, the Authors, published by Springer Nature.

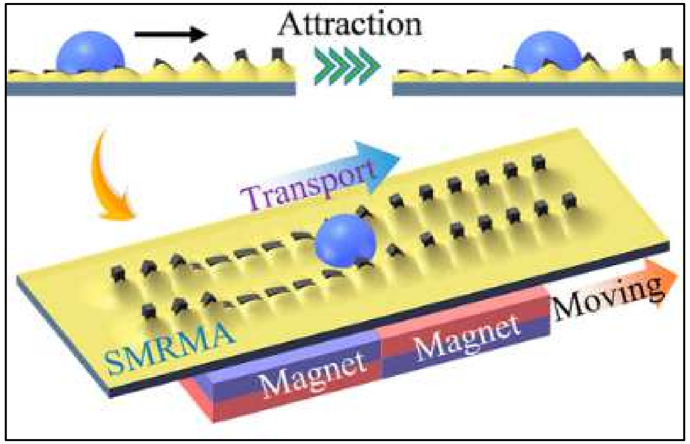
Slippery Lubricant-Infused Surfaces: Properties and Emerging Applications
Junsheng Li, Erica Ueda, Dorothea Paulssen, Pavel A. Levkin
Advanced Functionnal Materials 2018
https://doi.org/10.1002/adfm.201802317

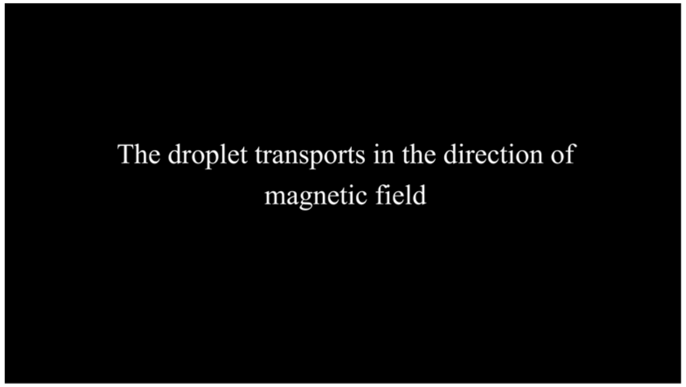
To conclude

- **Combining a liquid-infused surface and active macrostructures (2023)**

The larva *Pyrrhalta*







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« Active Droplet Transport Induced by Moving Meniscus on a Slippery Magnetic Responsive Micropillar Array » Yubin Peng, Chuanzong Li, Yunlong Jiao, Suwan Zhu, Yanlei Hu, Wei Xiong, Yaoyu Cao, Jiawen Li, Dong Wu, Langmuir, 2023 Apr 25;39(16):5901-5910. doi: 10.1021/acs.langmuir.3c00396

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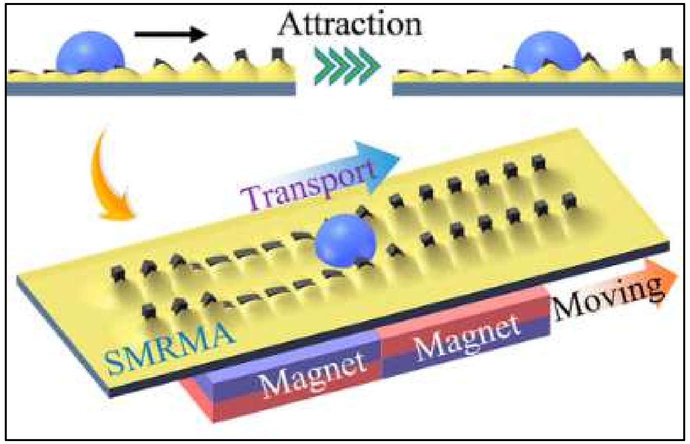

The droplet transports in the direction of magnetic field

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Thank you for your attention

Laurent Vonna

IIS2M - Institut de Science des Matériaux de Mulhouse
Université de Haute-Alsace

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The interdisciplinary thematic institutes of the University of Strasbourg & CNRS & Inserm funded under the Excellence Initiative program