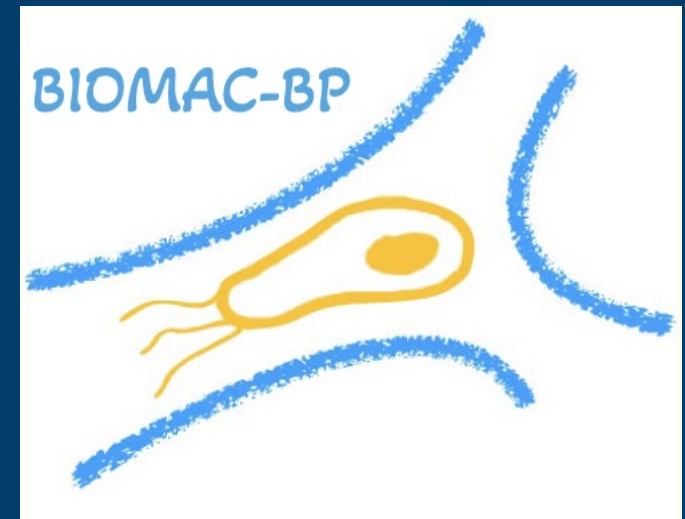


(BIO)2PHIM AND THEIR PHYSICO-CHEMICAL PROPERTIES

25.08.2025 | PETER LANG



2PHIM IN DAILY LIFE

Ubiquitous, e. g. in food and care formulations

Emulsions:



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stux - <http://pixabay.com/en/cream-skin-care-cream-colors-194126/>, CC0,
<https://commons.wikimedia.org/w/index.php?curid=37898285>



Tricia - CC BY-SA 2.0,
<https://commons.wikimedia.org/w/index.php?curid=19118083>

Foams:



https://commons.wikimedia.org/wiki/File:Crema_para_afeitar.JPG#Licensing;
CC-license



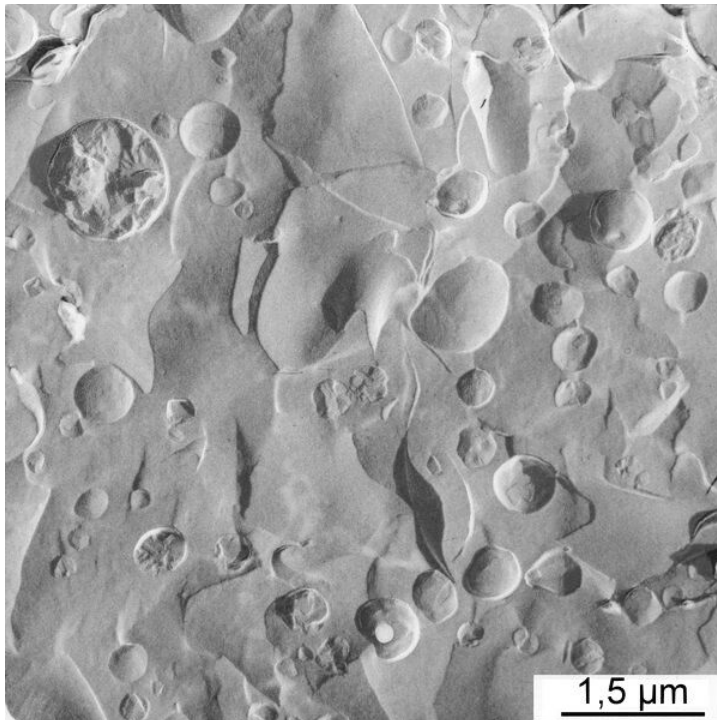
A. Mole - CC BY 2.0,
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Fire Brigade Neder-Betuwe, base Ochten, the Netherlands CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=3263914>

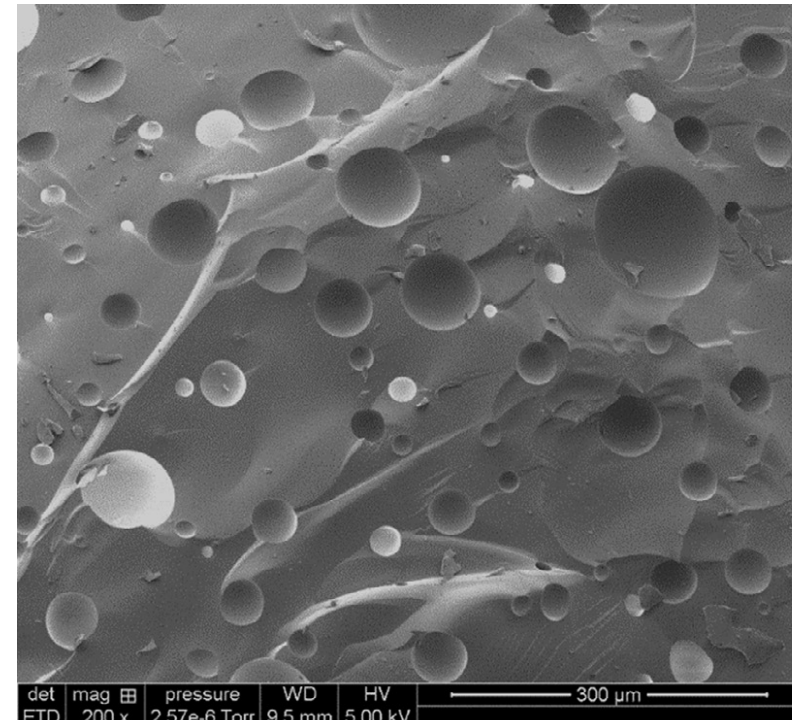
EMULSIONS AND FOAMS

Freeze fracture SEM of a
commercial skin care cream



Micrograph courtesy Markus Drechsler University Bayreuth

Freeze fracture SEM of a
PU foam before curing



Reignier et al J. Coll. Inter. Sci. 552, 153 (2019).

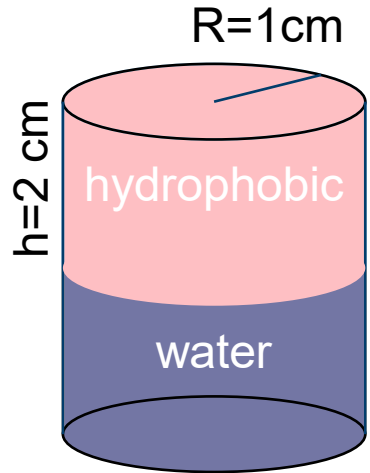
2PHIM: TWO PHASE HIGH INTERFACE MATERIALS

single droplet volume:

$$V_{sd} = \frac{4}{3}\pi a^3 = \frac{4}{3}\pi \mu\text{m}^3 = \frac{4}{3}\pi \times 10^{-12} \text{ cm}^3$$

single droplet interface area:

$$A_{sd} = 4\pi a^2 = 4\pi \mu\text{m}^2 = 4\pi \times 10^{-8} \text{ cm}^2$$

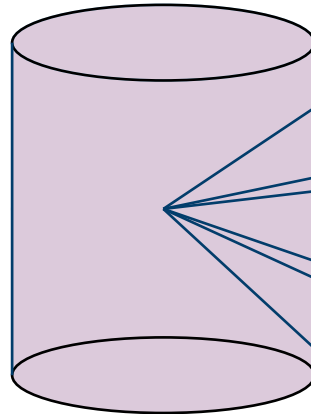


volume is conserved



droplet radius:

$$a = 1 \mu\text{m}$$



number of droplets:

$$N_d = \frac{V_t}{V_{sd}} = \frac{3 \times 10^{12}}{2}$$

total droplet interface area:

$$A_d = N_d \times A_{sd} = 6\pi \times 10^4 \text{ cm}^2$$

starting volume

$$V_t = h \times \pi R^2 = 2\pi \text{ cm}^3$$

starting interface area

$$A = \pi R^2 = \pi \text{ cm}^2$$

liquid

air

o/w emulsion

bubbles / foam

w/o emulsion

aerosol

bicontinuous
μ-emulsions
bijels

foam

INTERFACIAL TENSION



Von Andreas Hendrik - Selbst
fotografiert, Gemeinfrei,
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Von brokenchopstick - Flickr,
CC BY 2.0,
<https://commons.wikimedia.org/w/index.php?curid=627807>



S. Hoppe GFDL 2005
<https://commons.wikimedia.org/wiki/File:Wassertropfen.jpg?uselang=de>

Mechanical definition

Interfacial tension is the work it takes to create additional surface area

$$\gamma \equiv \frac{\delta W}{dA}$$



$$\delta W = F dx$$

$$dA = L dx \quad \gamma \equiv \frac{\delta W}{dA} = \frac{F}{2L}$$

units: force per length (mN/m)

$$\Delta G = G^{end} - G^{start} = \gamma (A^{end} - A^{start}) > 0$$

if $A^{end} > A^{start}$

Thermodynamic approach

$$G = H - TS$$

$$dG = dU + pdV + Vdp - dTS - SdT$$

$$dG = dq + \delta W_{\Delta V} + \delta W + pdV + Vdp - TdS - SdT$$

$$@ dp = 0 \text{ and } dT = 0$$

$$dG_{p,T} = \delta W_{\Delta V} + \delta W + pdV$$

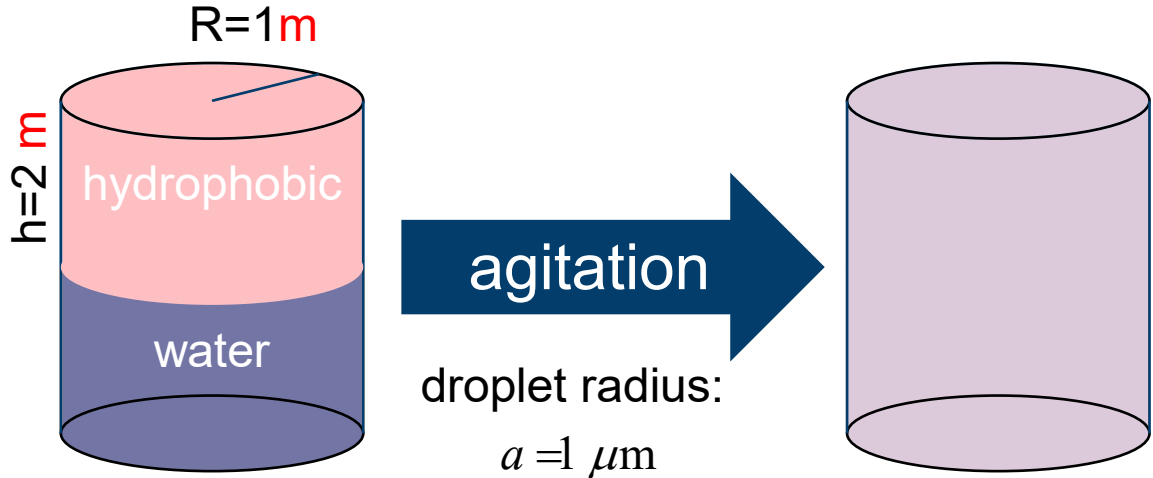
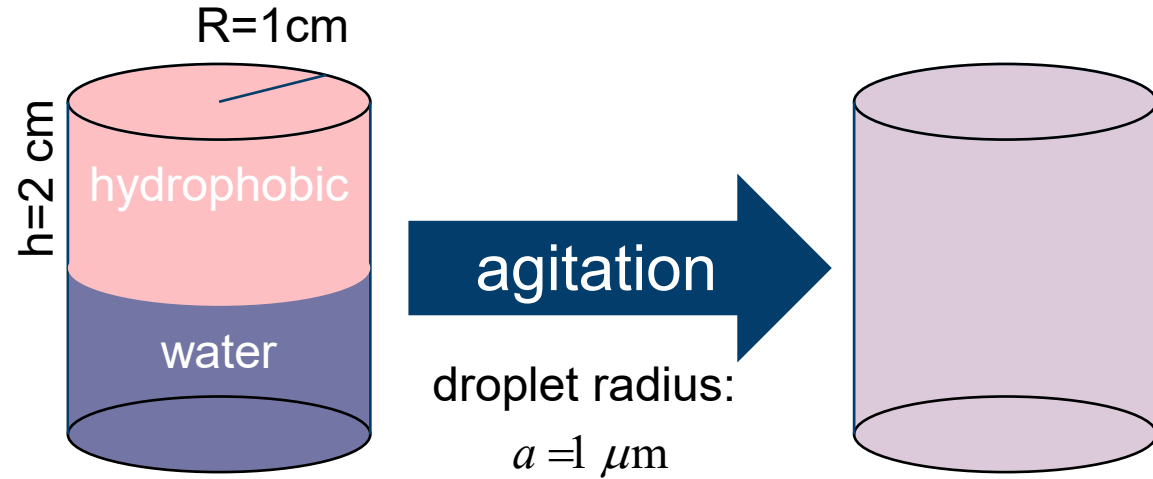
$$dG_{p,T} = -pdV + \delta W + pdV$$

$$\gamma = \frac{dG_{p,T}}{dA}$$

Change of free energy with area

INTERFACIAL TENSION

Practical considerations



Energie needed

$$\begin{aligned}\delta W &= \gamma \delta A \approx 40\text{ mN/m} \cdot 6\pi \times 10^4\text{ cm}^2 \\ &= 40 \times 10^{-3} \cdot 6\pi\text{ Nm} \\ &= 0.75\text{ J}\end{aligned}$$

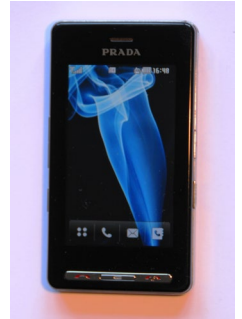
Microscopic level :
 $\delta W_d \approx 10^8 k_B T$ per droplet

$$k_B T \approx 4.1 \times 10^{-21}\text{ J at } T = 295\text{ K}$$

$$A_d \propto V_t \Rightarrow \delta W \propto V_t$$

volume scaling factor: 10^6

$$\begin{aligned}\delta W &= 0.75 \times 10^6\text{ J} \\ &= 750\text{ kJ}\end{aligned}$$



https://commons.wikimedia.org/wiki/File:LG_KE850_Prada_Hauptmen%C3%BC.jpg, GFDL

Sicherheitsoffizier ALÜ - PzLehrBtl 334
 "CELLE", Gemeinfrei,
<https://commons.wikimedia.org/w/index.php?curid=877386>



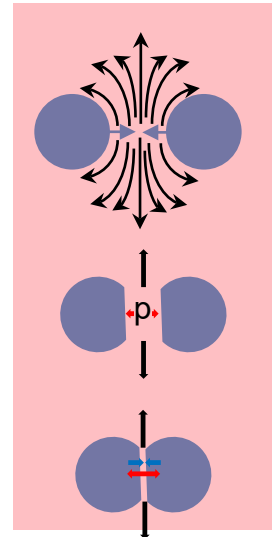
2PHIM INSTABILITY

Coalescence and colloidal droplet interactions

Droplets moving towards each other

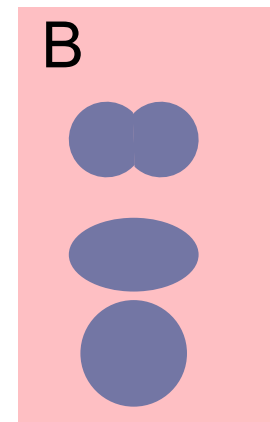
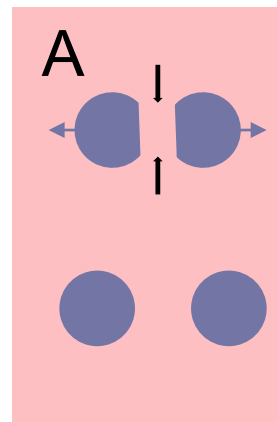
Flux causes disjoining pressure

Colloidal forces become active at small distance



A: disjoining pressure overcomes attractive DLVO forces, contact time smaller than drainage time

B: Attractive DLVO forces over-compensate disjoining pressure contact time larger than drainage time



By definition of the interfacial tension:

$$\Delta G_B = \gamma \Delta A$$

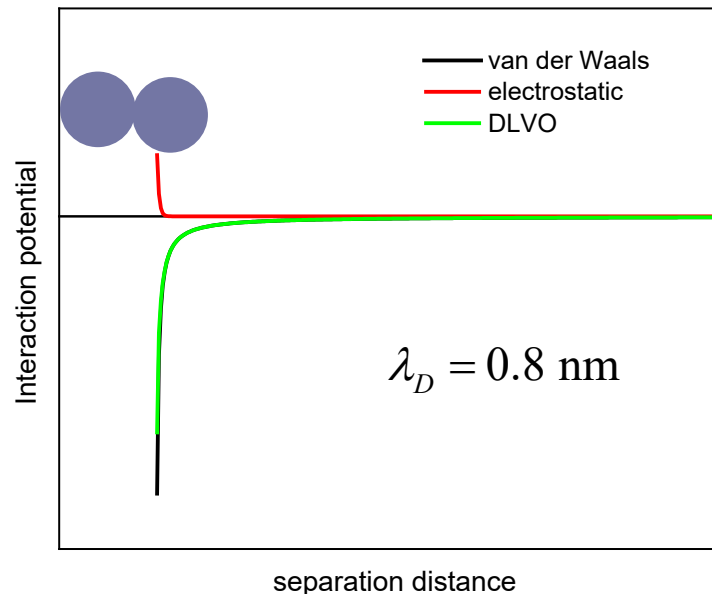
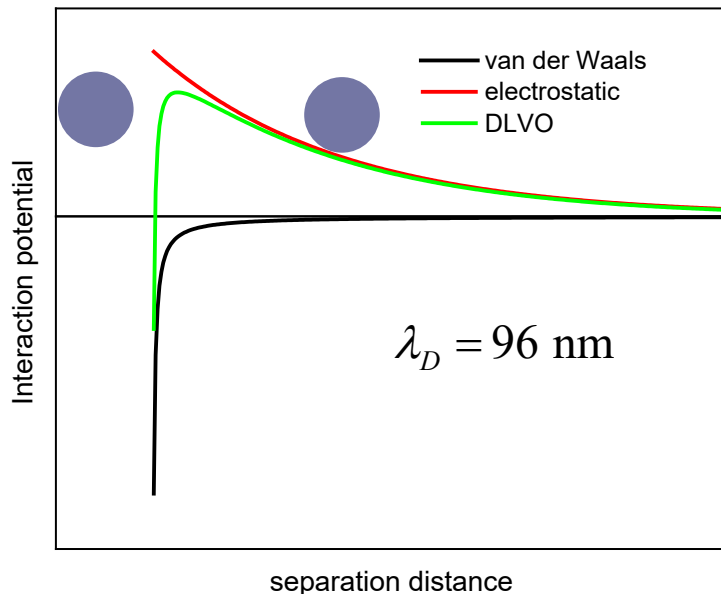
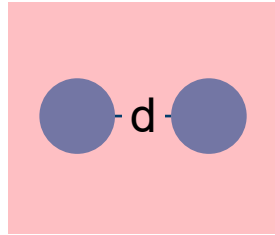
For two droplets of equal size:

$$\Delta G_B \approx -\gamma 0.2 A_{start}$$

2PHIM INSTABILITY

Coalescence and colloidal droplet interactions

DLVO interactions: Superposition of van der Waals and electrostatic interactions



DLVO in Derjaguin approximation

$$\frac{\Phi(d)}{k_B T} = -\frac{C_H a}{6d} + B_{er} \exp\left\{-\frac{d}{\lambda_D}\right\}$$

C_H : Hamaker constant, order of $k_B T$

B_{er} : electrostatic amplitude, function of charge density and particle size

λ_D : Debye length order 1 -100 nm
function of salt concentration

Type of electrolyte	example	λ_D / nm
1:1	NaCl	$\frac{0.304}{\sqrt{c_{salt}}}$
1:2 or 2:1	CaCl ₂	$\frac{0.176}{\sqrt{c_{salt}}}$
2:2	MgSO ₄	$\frac{0.152}{\sqrt{c_{salt}}}$

10^{-5} M NaCl solution: $\lambda_D = 96 \text{ nm}$

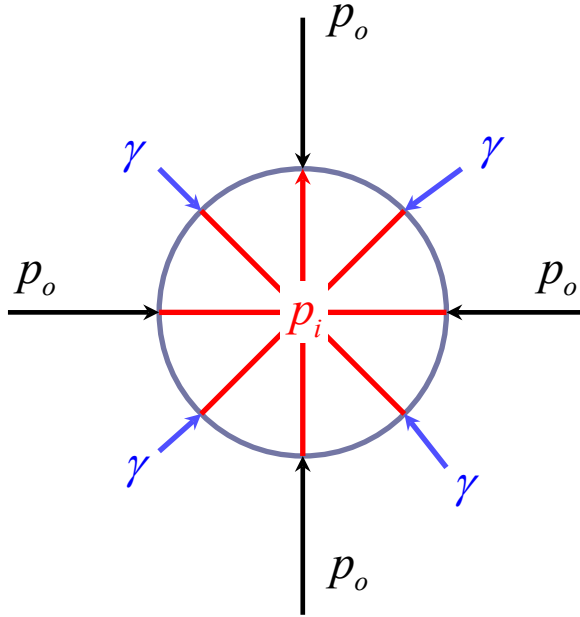
150 mM NaCl Solution: $\lambda_D = 0.8 \text{ nm}$

2PHIM INSTABILITY

Ostwald ripening



Von brokenchopstick - Flickr,
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Two forces acting from outside

- Ambient pressure
- Surface tension

Young-Laplace equation
for balancing inner pressure

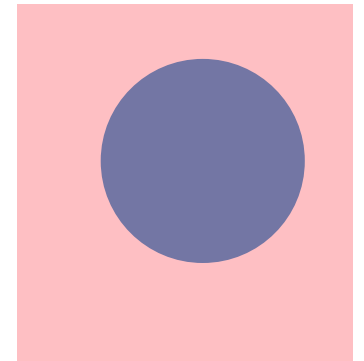
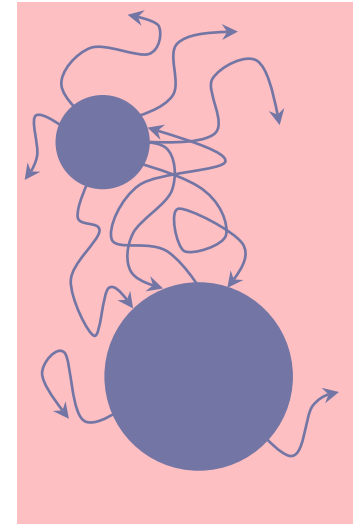
$$p_i = p_o \frac{2\gamma}{a}$$

Analogue for droplet emulsions

$$\mu(a) = \mu_\infty + \frac{2\gamma V_m}{a}$$

μ : chemical potential, measure for
the tendency of molecules
to leave the droplet

V_m : molar volume of dissolved molecules

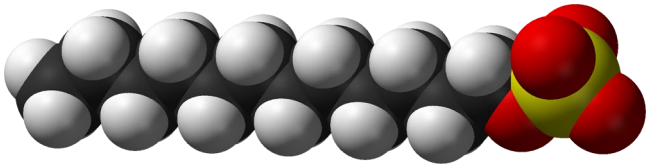
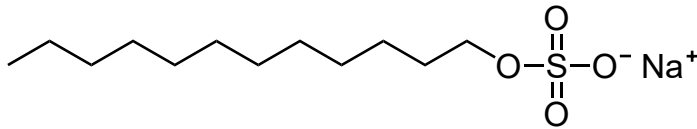
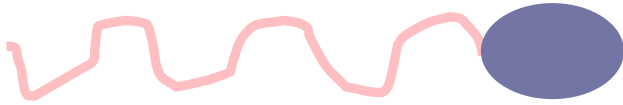


INCREASING STABILITY

Stabilizing compounds and mechanisms

Amphiphiles, surfactants

ἀμφί *amphí* „both sides“ and
φίλος *phílos* „loving“



sodium dodecyl sulfate, SDS

Reduction of the interfacial tension
due to amphiphile adsorption

Interface excess: $\Gamma = N/A$
number of excess molecules per unit area

Gibbs adsorption equation: $\Gamma = -\frac{1}{RT} \left(\frac{\partial \gamma}{\partial \ln c} \right)$

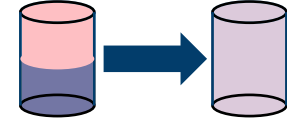
Langmuir adsorption isotherm: $\Gamma \propto c$

$$\longrightarrow \longrightarrow \frac{d\gamma}{dN} = -\frac{RT}{A} \text{ units } \left[\frac{J}{\text{mol m}^2} \right]$$

On the single molecule level:

$$\left(\frac{d\gamma}{dN} \right)_{sm} = -\frac{RT}{N_A A_{sm}} = -\frac{k_B T}{A_{sm}} \text{ units } \left[\frac{J}{\text{m}^2} \right]$$

Reduction of interfacial
tension per droplet:



$$a = 1 \mu\text{m}$$

$$A_d = 4\pi \times 10^6 \text{ nm}^2$$

$$A_{sm} \approx 0.5 \text{ nm}^2$$

Number of surfactant
molecules per droplet:

$$N_{sm} = A_d / A_{sm} = 8\pi \times 10^6$$

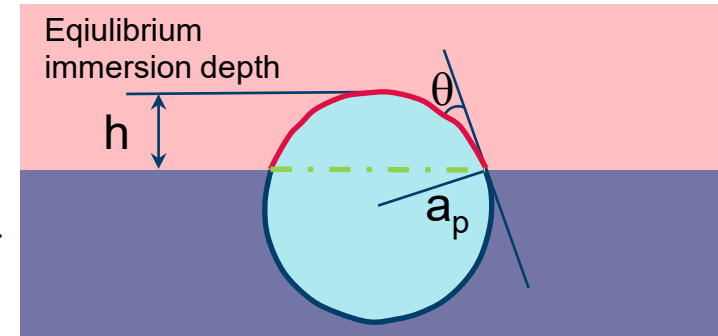
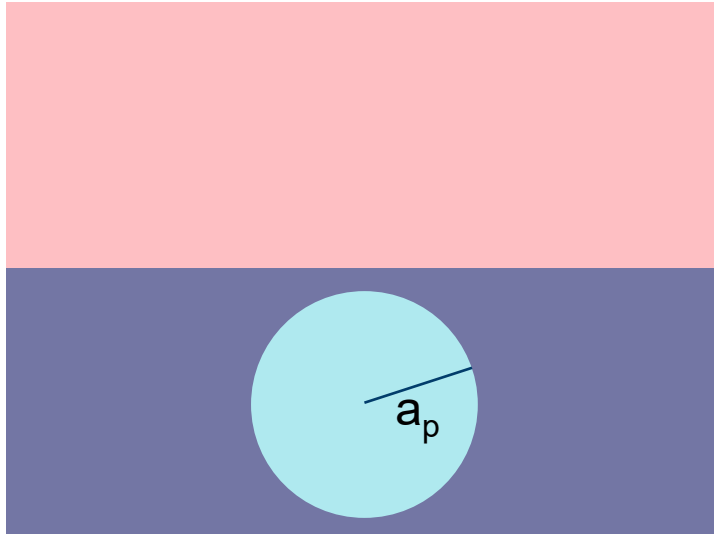
$$\begin{aligned} \left(\frac{d\gamma}{dN} \right)_d &= -N_{sm} \frac{k_B T}{A_{sm}} \\ &\approx 2.5 \times 10^7 k_B T \\ &\approx 0.25 \delta W_d \end{aligned}$$

INCREASING STABILITY

Stabilizing compounds and mechanisms

Colloidal particles

Pickering-Ramsden 2PHIM



$$A_{h,p} = 2\pi a_p h$$

$$A_{h,w}^{removed} = \pi(2a_p h - h^2)$$

$$A_{w,p} = A_p - 2\pi a_p h$$

$$\Delta G = ?$$

$$\Delta G = G^{end} - G^{start}$$

$$= \gamma_{h,p} A_{h,p} + \gamma_{w,p} A_{w,p} - \gamma_{h,w} A_{h,w}^{removed} - \gamma_{w,p} A_p + \gamma_{h,w} (A_{h,w}^{end} - A_{h,w}^{start})$$

$$= 2\pi a_p h (\gamma_{h,p} - \gamma_{w,p}) - \pi(2a_p h - h^2) \gamma_{h,w} \text{ general with } A_{h,w}^{end} \approx A_{h,e}^{start}$$

Interfacial free energy of the h/w interface

$$G_{h,w} = \gamma A_{h,w}$$

Interfacial free energy of the particle

$$G_{w,p} = \gamma_{w,p} A_p = \gamma_{w,p} 4\pi a_p^2$$

Maximum negative if $\gamma_{h,p} = \gamma_{w,p} \Rightarrow h = a_p$

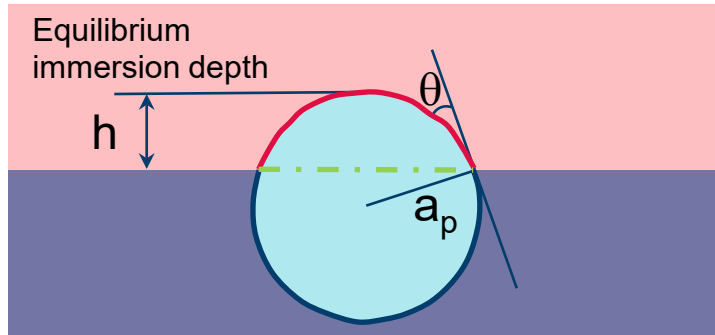
$$\Delta G_{\max} = -\pi a_p^2 \gamma_{h,w}$$

INCREASING STABILITY

Stabilizing compounds and mechanisms

Colloidal particles

Pickering-Ramsden 2PHIM



$$\Delta G = G^{end} - G^{start}$$

$$\begin{aligned} &= \gamma_{h,p} A_{h,p} + \gamma_{w,p} A_{w,p} - \gamma_{h,w} A_{h,w} - \gamma_{w,p} A_p \\ &= 2\pi a_p h (\gamma_{h,p} - \gamma_{w,p}) - \pi (2a_p h - h^2) \gamma_{h,w} \end{aligned}$$

Maximum negative if $\gamma_{h,p} = \gamma_{w,p} \Rightarrow h = a_p$

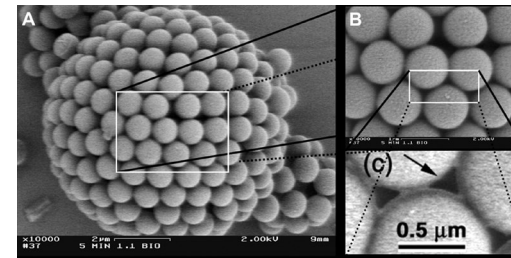
$$\Delta G_{\max} = -\pi a_p^2 \gamma_{h,w}$$

Free energy gain on single particle level

$$\begin{aligned} \gamma_{h,w} &\approx 40 \text{ mN/m} & \Delta G_p &= -40\pi (100 \times 10^{-9})^2 \text{ mNm} \\ a_p &= 100 \text{ nm} & &\approx -3 \times 10^5 k_B T \end{aligned}$$

Free energy gain on droplet level

Experiments show full interface coverage by particles



$$N_p = Q \frac{4a^2}{a_p^2}$$

$$\begin{aligned} \Delta\text{-lattice: } Q &= \frac{\pi}{4} \\ \square\text{-lattice: } Q &= \frac{\pi}{2\sqrt{3}} \end{aligned}$$

Dinsmore et al,
Science 298, 1006-1009 (2002).
DOI: 10.1126/science

$$\begin{aligned} \Delta G_d &\approx N_p \Delta G_p = -Q \frac{4a^2}{a_p^2} \pi a_p^2 \gamma_{h,w} = -Q A_d \gamma_{h,w} \\ &= -Q \delta W_d \end{aligned}$$

Synthetic and biological examples

CCCCCCCCOS(=O)(=O)[O-].[Na+]CCCCCCCCCCCCOCCOCCOCCOCCOCCCCCCCCCCCCCCCC[N+](C)(C)CCCCCCCCCCCCCCCCCC(=O)OCCOP(=O)([O-])OCC[N+](C)(C)C

detergents,
softeners, personal
care products
pharmaceutical ...

CCCCCCCCCCCCCCCC(=O)OCCO[illegible]C[N+](C)(C)CCOP(=O)([O-])OCCOC(=O)R1COC(=O)R2

A detailed anatomical diagram of the human urinary system. It shows two kidneys at the top, each with a renal pelvis and renal pyramids. The renal pelvises lead into the ureters, which descend to the bladder. The bladder has a trigone and a urethra. The diagram is color-coded: blue for the ureters and urethra, red for the renal pelvis and ureters, and green for the renal pyramids. The entire system is set against a light blue background.



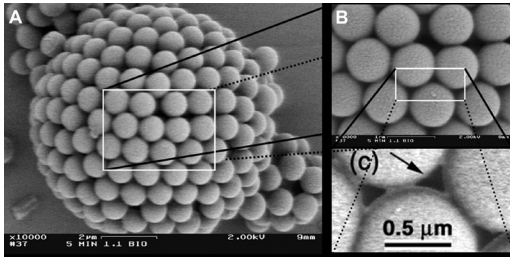
STABILIZING COMPOUNDS

Synthetic and biological examples

Colloidal particles (Pickering 1907; Ramsden 1903)

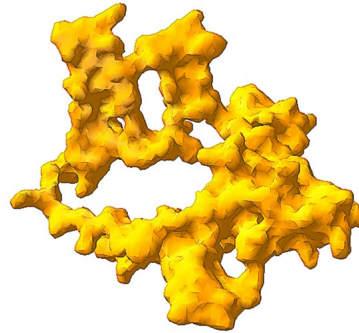
Synthetic particles

- silica
- polystyrene
- etc.



Proteins

- e. g. caseins

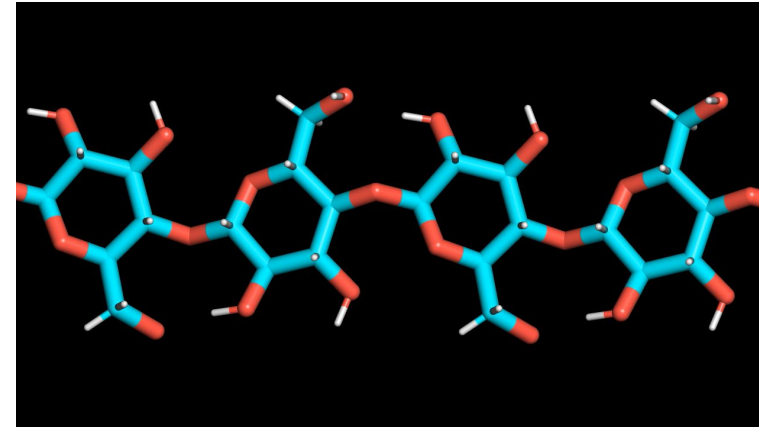


José Manuel Ageitos GFDL
https://en.wikipedia.org/wiki/File:K-case%C3%ADna_comic.jpg

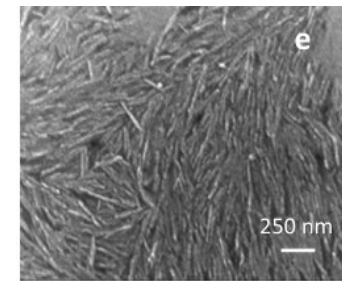


Stefan Kühn, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=23754>

Cellulose (starch) nano-crystals



Animation courtesy Wim Thielemans



Parajuli et al, "Fundamental aspects of nanocellulose stabilized Pickering emulsions and foams"
Advances in Colloid and Interface Science 299 (2022) 102530

Applications

- enhanced oil recovery
- waste water remediation
- pharmaceutical formulations (due to stability under gastric conditions)

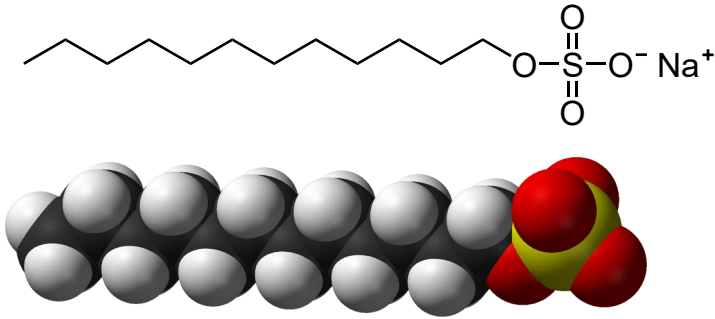
Applications:

- reinforcing fillers in nano-composites
- food formulations
- pharmaceutical formulations

STABILISATION MECHANISMS

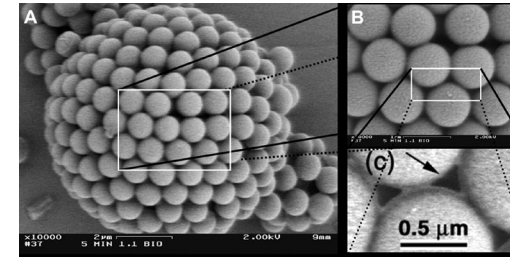
Wrap up

Surfactants



- Reduced surface tension
 - reduces coalescence
 - reduces Ostwald ripening
- Electrostatic repulsion
 - reduces coalescence
- Molecular adsorption energy
 - order $k_B T$

Colloidal particles



Dinsmore et al,
Science 298, 1006-1009 (2002).
DOI: 10.1126/science

- Reduced surface free energy
- Steric repulsion
 - reduces coalescence ($d > 2a_p$)
 - reduces Ostwald ripening (reduced h,w interface)
- Particle adsorption energy
 - order $10^{5-6} k_B T$

STABILITY

Kinetic vs thermodynamic

Boltzmann:

$$p_{con} \propto \exp\{-E_a\}$$

Thermodynamically unstable dispersion

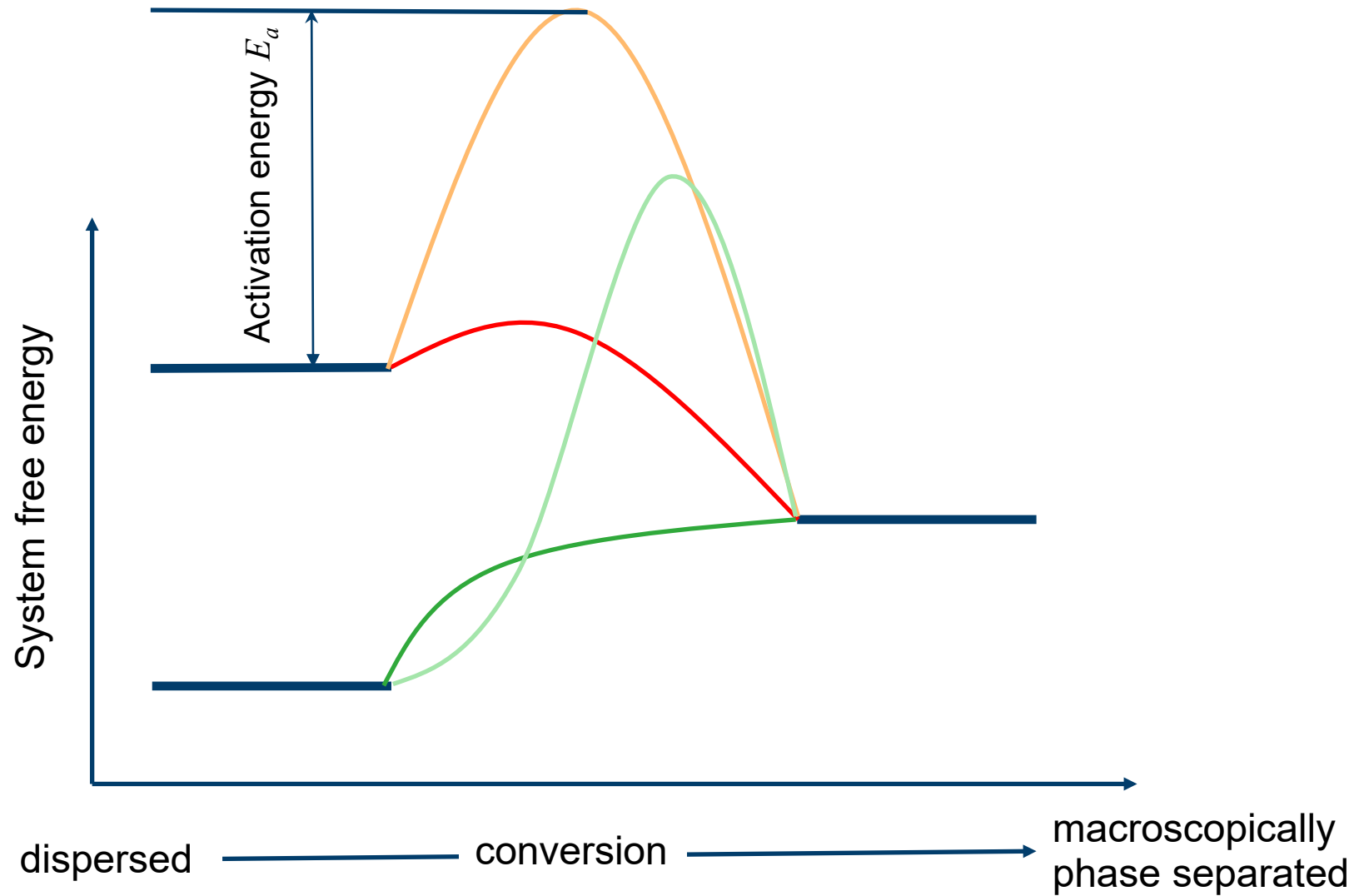
— $\Delta G < 0$, small E_a spontaneous phase separation

— $\Delta G < 0$, large E_a
Kinetically stable dispersion

Thermodynamically stable dispersion

— $\Delta G > 0$ no E_a for dispersion spontaneous

— $\Delta G > 0$ large E_a for dispersion kinetically hindered



STABILITY

Kinetic vs thermodynamic

Change of free system energy due to dispersion: $\Delta G = \gamma \Delta A - T \Delta S$

Thermodynamic stability requires: $\Delta G < 0$

Dispersion of a given volume:

Decreasing droplet size

- increasing number of droplets $N_d \rightarrow$ increasing entropy
- increasing total surface of dispersed phase $A_d \rightarrow$ increasing ΔA

$$\Delta G = \gamma (A^{end} - A^{start}) - T (S^{end} - S^{start}) \approx \gamma A^{end} - T S^{end} \quad \text{assuming that} \quad \begin{matrix} A^{end} \gg A^{start} \\ S^{end} \gg S^{start} \end{matrix}$$

Entropy of an ideal gas
(dilute suspension of
non interacting droplets)

$$S^{end} = N_d k_B \ln \left(\frac{e^{2.5} V}{N_d \Lambda_B^3} \right)$$

V : volume of the continuous phase

$$\Lambda_B = \frac{h}{\sqrt{2\pi m k_B T}} \quad \text{de Broglie wavelength}$$

m : droplet mass

h : Planck constant

STABILITY

Kinetic vs thermodynamic

Gedankenexperiment: disperse 2π mL oil with mass density (0.95 g/mL) in 1L water

$$\Delta G = \gamma A^{end} - TN_d k_B \ln \left(\frac{e^{2.5V}}{N_d \Lambda_B^3} \right)$$

Large droplets $a = 1 \mu\text{m}$

$$N_d = 1.5 \times 10^{12}$$

$$\Lambda_B \approx 2.9 \times 10^{-16} \text{ m}$$

$$\ln \left(\frac{e^{2.5V}}{N_d \Lambda_B^3} \right) \approx 75$$

$$A^{end} = 6\pi \text{ m}^2$$

$$\gamma = 40 \text{ mN/m}$$

$$S^{end} \approx 4.5 \times 10^{-7} \text{ J/K} \quad \gamma A^{end} = 0.75 \text{ J}$$

$$\Delta G = (0.75 - 295 \times 4.5 \times 10^{-7}) \text{ J} \approx 0.75 \text{ J}$$

Small droplets $a = 10 \text{ nm}$

$$N_d = 1.5 \times 10^{18}$$

$$\Lambda_B \approx 2.9 \times 10^{-13} \text{ m}$$

$$\ln \left(\frac{e^{2.5V}}{N_d \Lambda_B^3} \right) \approx 40$$

$$A^{end} = 6\pi \times 10^2 \text{ m}^2$$

$$\gamma = 40 \text{ mN/m}$$

$$S^{end} \approx 2.5 \times 10^{-1} \text{ J/K} \quad \gamma A^{end} = 75 \text{ J}$$

$$\Delta G = (75 - 295 \times 0.25) \text{ J} \approx 1 \text{ J}$$

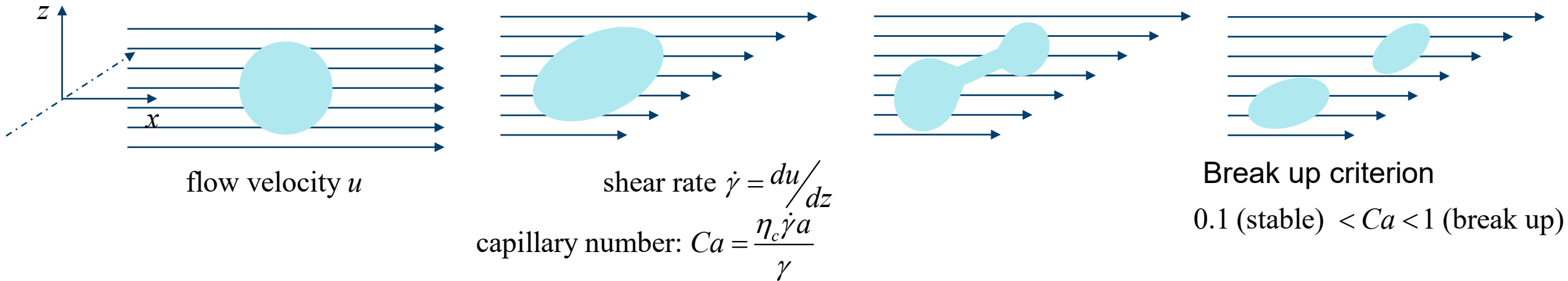
Only for very small droplets or very low surface tension the entropy term cannot overcompensate the energy term
Emulsions are always instable over time or kinetically stable (PR)

PREPARATION OF 2PHIM

Stirring, shaking, etc. causes flow, velocity gradients eddies ...

Simplest case: laminar flow

with velocity gradient



here: $a = 1 \text{ } \mu\text{m}$, $\eta_c = 1 \text{ mPa s}$, $\gamma = 40 \text{ mN/m}$

$$\dot{\gamma}_{break} \approx \frac{\gamma}{a\eta_c} = 4 \times 10^7 \text{ s}^{-1}$$

Typical water pipe: $\dot{\gamma} \approx 20 \text{ s}^{-1}$

Turbulent flow, Hinze scale

$$R_{\max} \approx C \left(\frac{\gamma}{\rho_c} \right)^{3/5} \varepsilon^{-2/5}$$

C : empirical constant 0.7-0.8

ρ_c : mass density of continuous phase

ε : energy dissipation rate

$\varepsilon \approx 10 \text{ Js/kg}$ regular lab stirrer

$$\begin{aligned} R_{\max} &= 0.0211 \gamma^{3/5} \\ &= 690 \text{ } \mu\text{m} @ \gamma = 40 \text{ mN/m} \\ &= 7.5 \text{ } \mu\text{m} @ \gamma = 1 \text{ mN/m} \end{aligned}$$

PREPARATION OF 2PHIM



Stator rotator mixers

turbulent flow by stirring

Typical droplet size 1-10 μm

Chris 73 / Wikimedia Commons, CC
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<https://commons.wikimedia.org/w/index.php?curid=19672>



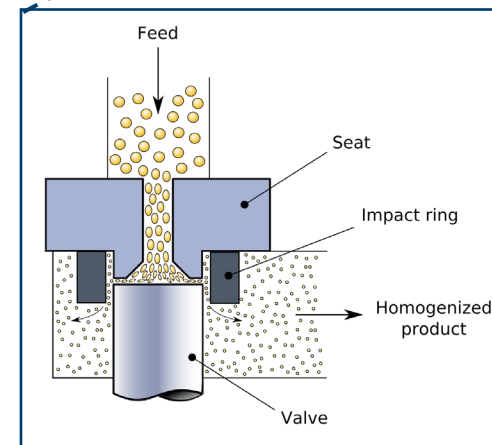
Image: THALETEC GmbH – BE-type enameled mixing tank with a volume of 16,000 l – www.thaletic.com

Mitglied der Helmholtz-Gemeinschaft

High pressure homogenizers

Turbulent flow by small slits or nozzles

Typical droplet size 100nm- 1 μm



PREPARATION OF 2PHIM

Ultrasonic homogenizers

Turbulent flow by sound waves

Typical droplet size 100nm- 5 μ m

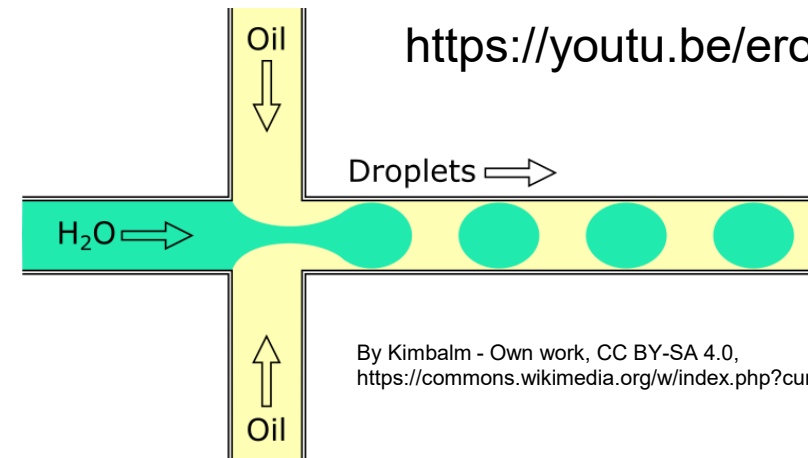


<https://ussolid.com/products/1000-w-2-in-1-ultrasonic-homogenizer-ultrasonicator-cell-disruptor-mixer-integrated-type-copy>

Droplet microfluidics

Uniform break up by pressure pulses

Typical droplet size <100nm

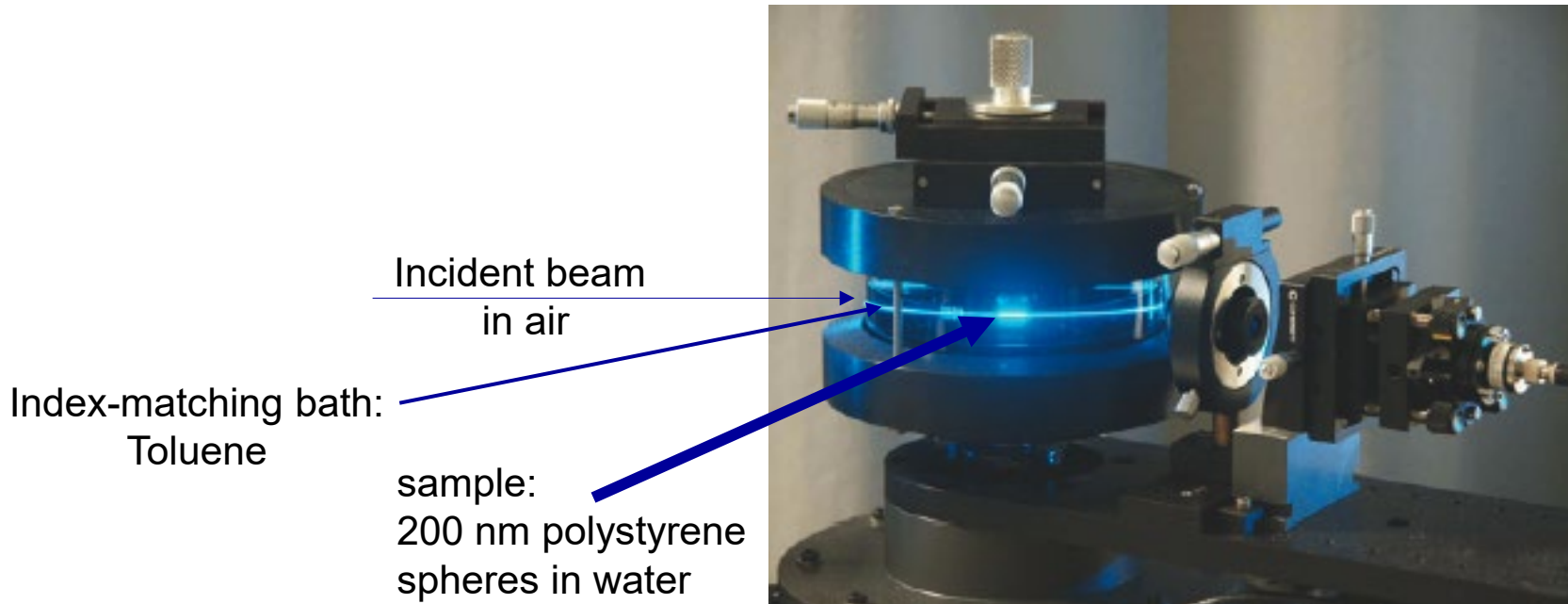


<https://youtu.be/eroy6zjf8HE>

By Kimbalm - Own work, CC BY-SA 4.0,
<https://commons.wikimedia.org/w/index.php?curid=91060642>

CHARACTERIZATION OF 2PHIM

- Rheometry: mechanical properties (dedicated lectures and lab courses)
- Microscopy: Droplet size and distribution (dedicated lectures and lab courses)
- Light scattering: Droplet size and distribution



$$\frac{I_S}{I_I} \frac{d_{DS}^2}{V_S} \propto \rho V_p^2 K \quad \text{general}$$

I_I : incident intensity

d_{SD} : sample to detector distance

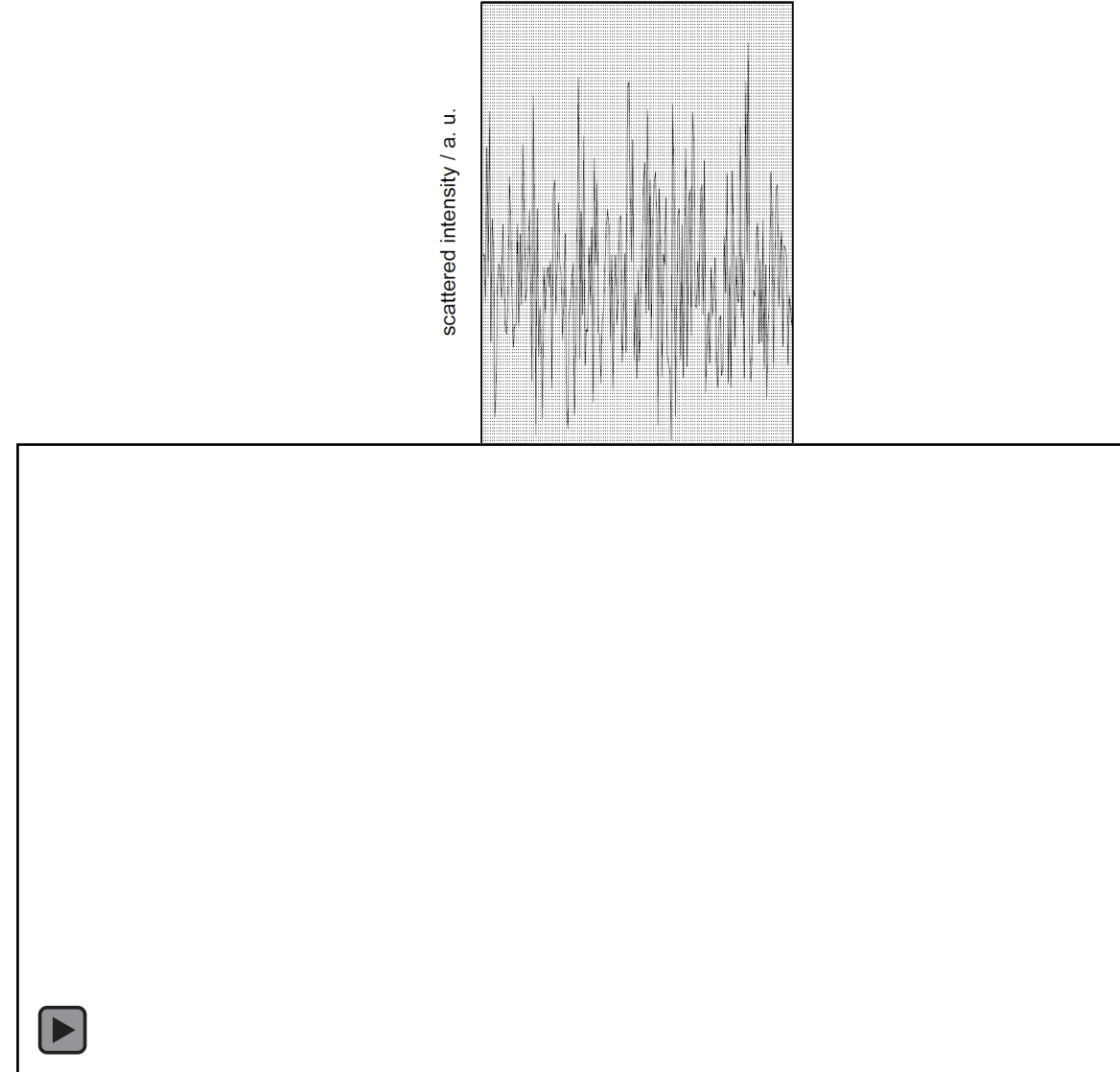
V_S : scattering volume

ρ : number density

V_p : single particle volume

K : contrast factor

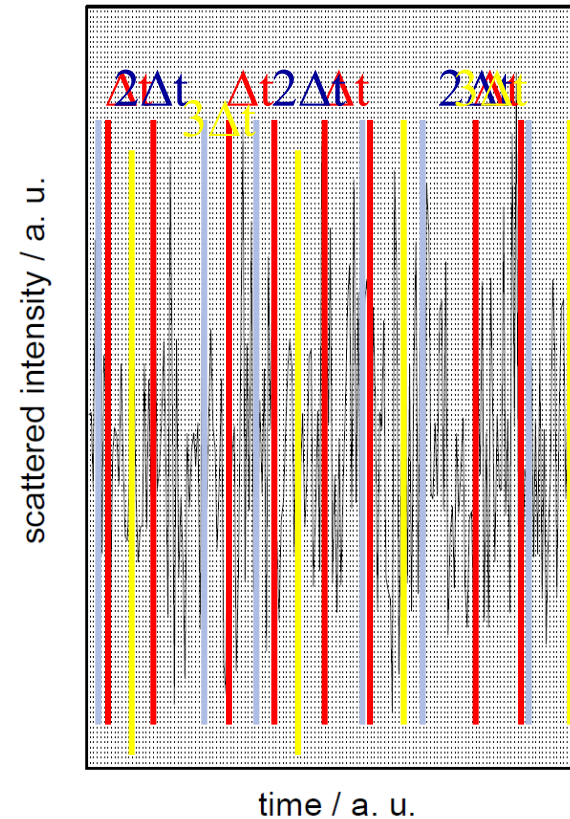
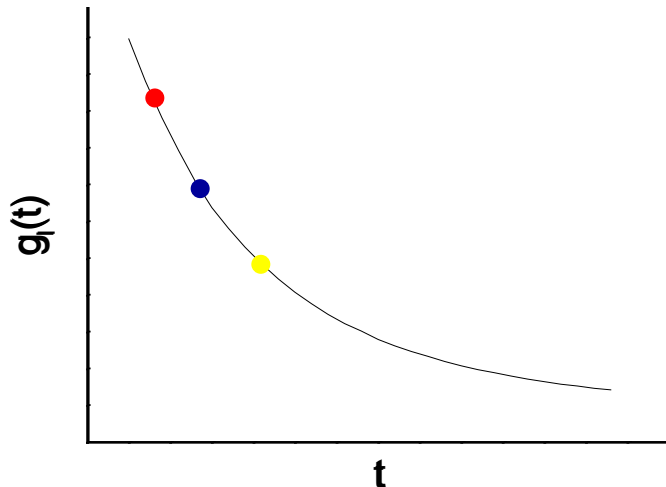
DYNAMIC LIGHT SCATTERING



DYNAMIC LIGHT SCATTERING

$$g_I(Q, t) \propto \langle I_S(Q, 0) I_S(Q, t) \rangle$$

$$g_I(q, 1 \times \Delta t) = \frac{1}{M+1} \sum_{n=0}^M \langle I(q, n \times \Delta t) I(q, (n+1) \times \Delta t) \rangle$$



Normalisation:

$$\hat{g}_I(Q, t) = g_I(Q, t) / \langle I(Q) \rangle^2$$

For ideally spherical particles with uniform size

$$\hat{g}_I(Q, t) = 1 + \beta \exp\{-2D_0 Q^2 t\}$$

$$D_0 = \frac{k_B T}{6\pi\eta_S R_H}$$

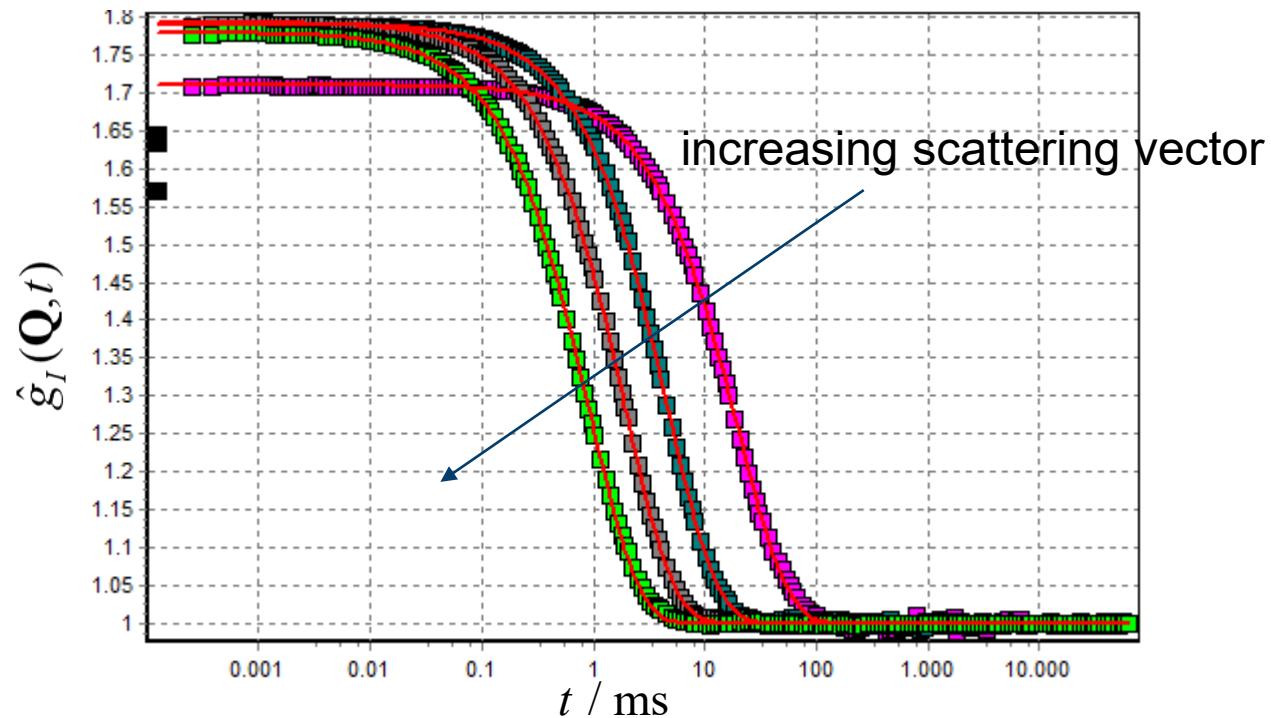
R_H : hydrodynamic radius

DYNAMIC LIGHT SCATTERING

Data analysis

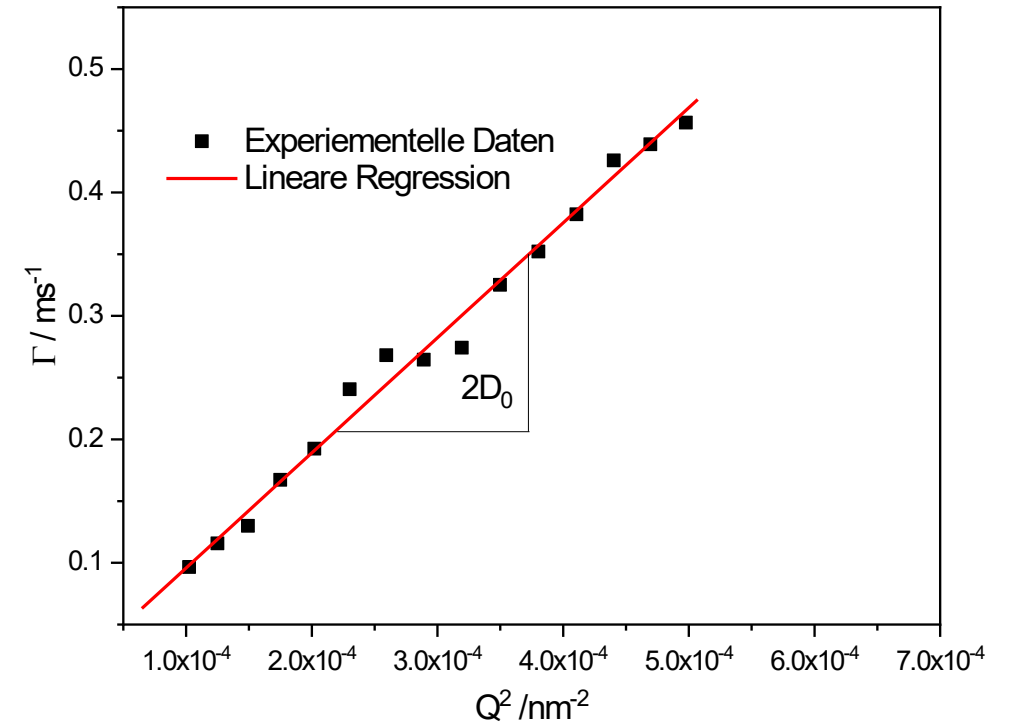
Spherical particles with uniform size

Non-linear least squares fitting with $\hat{g}_I(Q, t) = 1 + \beta \exp\{-\Gamma t\}$



$$\Gamma = 2D_0Q^2$$
$$R_H = \frac{k_B T}{6\pi\eta D_0}$$

Stokes Einstein
 $R_H = 468$ nm
 $a = 475$ nm
(TEM)



DYNAMIC LIGHT SCATTERING

Data analysis

For particles/droplets with size distribution: $\hat{g}_I^{\text{exp}}(Q,t) = 1 + \beta \sum_i w_i g_i(Q,t)$

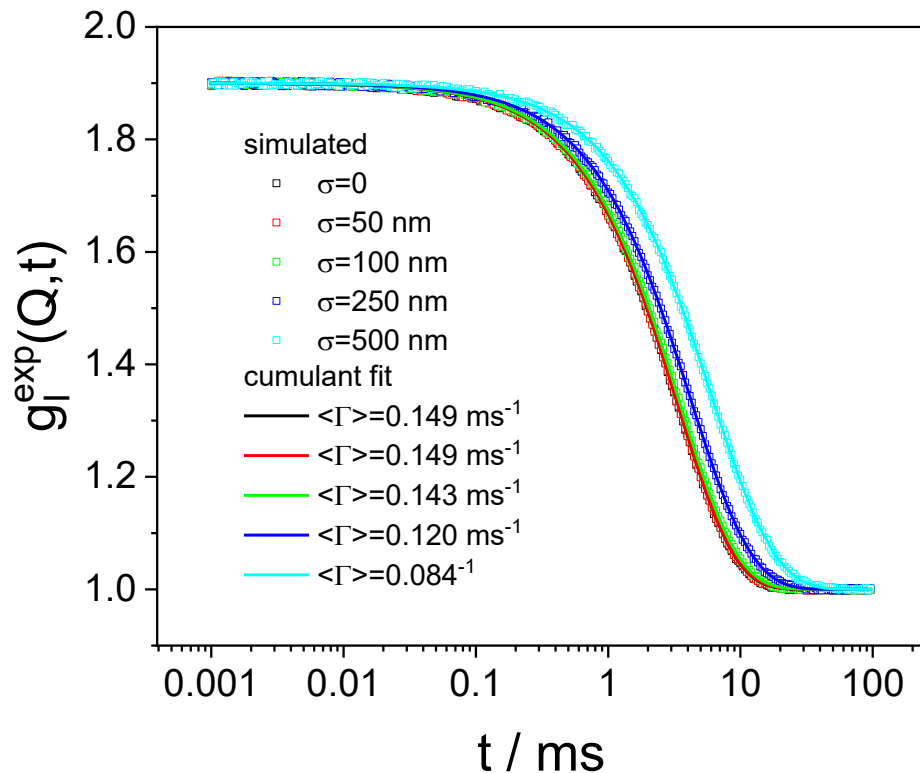
Input: simulated TCF

$\langle a \rangle = 500$ nm, various standard deviations σ

$$\approx 1 + \beta \int_0^\infty \Psi(\Gamma) \exp\{\Gamma t\} dt$$

Cumulant method $\hat{g}_I^{\text{exp}}(Q, t) = \exp\{-2\langle\Gamma\rangle t\} \left(1 + \frac{\mu_2}{2!} t^2 + \frac{\mu_3}{3!} t^3 + \dots\right)^2$

$$? \langle R_H \rangle \equiv \frac{Q^2}{\langle \Gamma \rangle} \frac{k_B T}{6\pi\eta} \approx \langle a \rangle ? \quad \begin{array}{l} \langle \Gamma \rangle : \text{average relaxation rate} \\ \mu_2 : \text{variance} \end{array}$$



σ	$\langle \Gamma \rangle / \text{ms}^{-1}$	$\langle R_H \rangle / \text{nm}$	$\langle R_H \rangle / \langle a \rangle$
0	0.149	501	1
50	0.149	501	1
100	0.143	520	1.04
250	0.120	621	1.24
500	0.084	891	1.78

DYNAMIC LIGHT SCATTERING

Data analysis

For particles/droplets with size distribution:

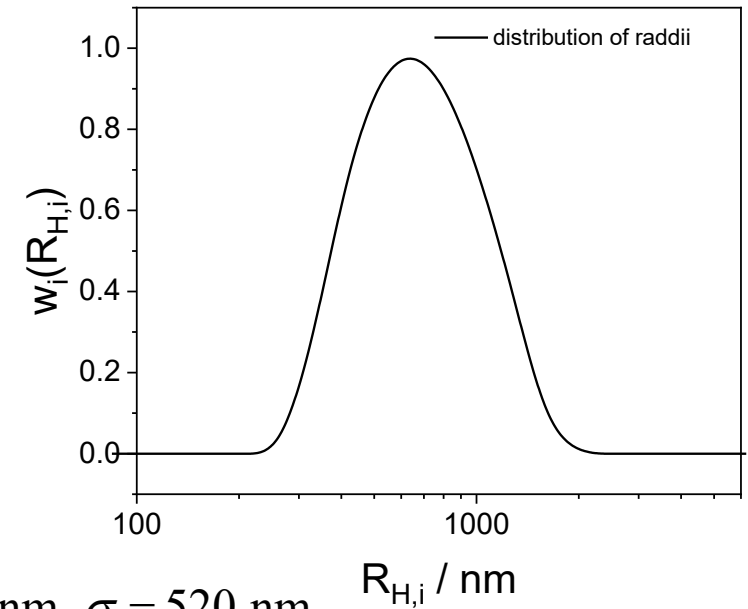
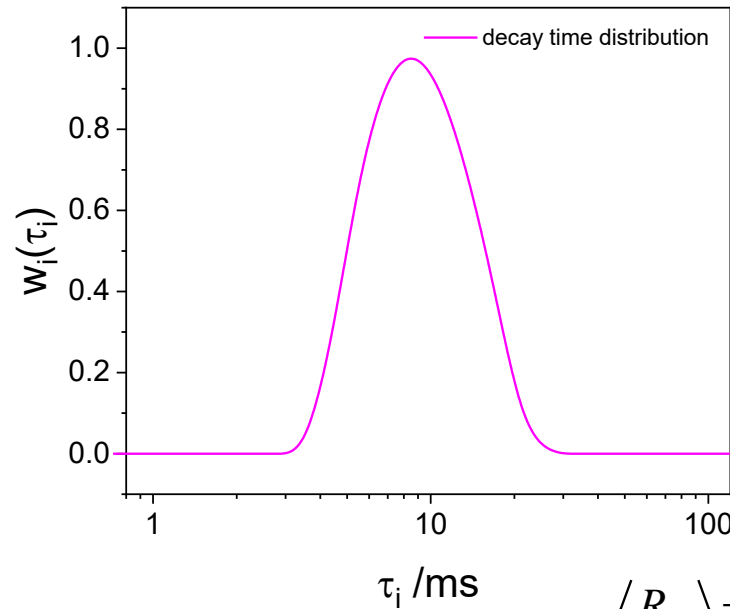
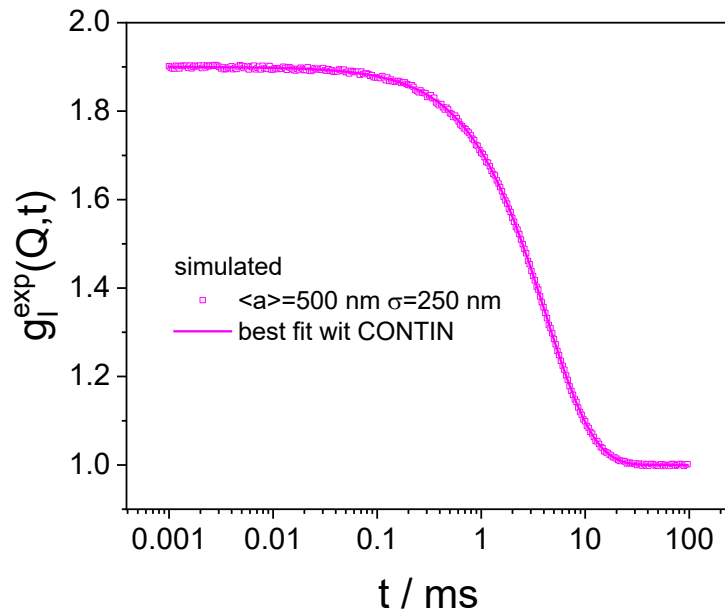
CONTIN:

$$\hat{g}_I^{\text{exp}}(Q, t) = 1 + \beta \sum_i g_i(Q, t)$$

$$\hat{g}_I^{\text{exp}}(Q, t) = 1 + \beta \sum_{i=1}^N w_i \exp \left\{ -\frac{tQ^2}{\tau_i} \right\}$$

$$R_{H,i} = \tau_i \frac{k_B T}{6\pi\eta} Q^2$$

τ_i : relaxation time of particles with radius a_i



$$\langle R_H \rangle = 670 \text{ nm}, \sigma = 520 \text{ nm}$$

$$\frac{\langle R_H \rangle}{\langle a \rangle} = 1.4$$

CONCLUSIONS

- 2PHIM are ubiquitous
- Generally unstable due to surface tension
- Pickering Ramsden 2PHIM
 - kinetically stable
 - advantageous mechanical properties
- Characterization
 - microscopy
 - rheometry
 - light scattering (be careful about the numbers)