

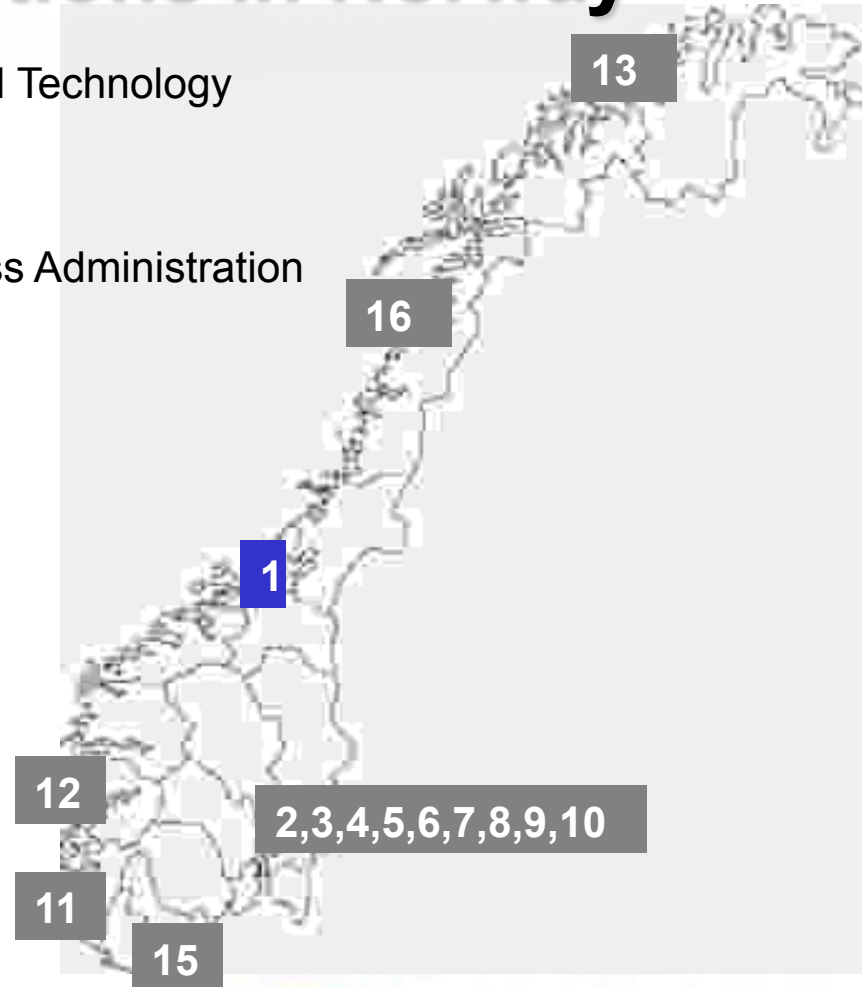
# Soft Nano Science/Technology

**Jon Otto Fossum**

**Norwegian University of Science and Technology - NTNU  
Trondheim  
Norway**

# University-level institutions in Norway

- 1) **NTNU** – Norwegian University of Science and Technology
- 2) University of Oslo
- 3) Norwegian University of Life Sciences
- 4) Norwegian School of Economics and Business Administration
- 5) Norwegian School of Sport Sciences
- 6) The Oslo School of Architecture and Design
- 7) The Norwegian Academy of Music
- 8) The Norwegian School of Veterinary Science
- 9) UniK – University Graduate Centre, Kjeller
- 10) The Norwegian Lutheran School of Theology
- 11) University of Stavanger
- 12) University of Bergen
- 13) University of Tromsø
- 14) The University Centre in Svalbard
- 15) University of Agder
- 16) University of Nordland



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

# Academic history

- 1217 Schola Cathedralis Nidrosiensis
- 1760 Royal Norwegian Society of Sciences and Letters
- 1910 Norwegian Institute of Technology (NTH)
- 1922 Norwegian Teachers' College [in Trondheim] (NLHT)
- 1950 SINTEF (the Foundation for Technical and Industrial Research at NTH)
- 1955 Norwegian Academy of Technological Sciences (NTVA) (Trondheim)
- 1968 University in Trondheim (UNIT)
- 1973 Trøndelag Music Conservatory
- 1974 Department of Medicine (from 1984: The Faculty of Medicine)
- 1979 Trondheim Academy of Fine Art
- 1980 Norwegian College of General Sciences (AVH) (previously NLHT)
- 1994 University Colleges in Sør-Trøndelag, Gjøvik and Ålesund are established
- 1996 Norwegian University of Science and Technology
- 2010 Trondheim celebrates 250 years as an academic city
- 2016 University Colleges in Sør-Trøndelag, Gjøvik and Ålesund merge with NTNU

# University for technology and the arts

**Norway's primary institution for educating MSc/PhD-level engineers and scientists.**

Also comprehensive programmes in social sciences, teacher education, the arts and humanities, medicine, architecture and fine arts.



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

# Fields of study

- MSc-level Engineering and Architecture
- Aesthetics, Fine Art and Music Studies
- Medicine, Health and Social Studies.
- History, Religion, Culture and Ideas
- Sport Sciences
- Information Technology and Informatics
- Teacher Education
- Media Studies and Communication
- Economics and Administration
- Pedagogy
- **Mathematics and Natural Sciences**
- Social Sciences and Psychology
- Languages and Literature



- 14 faculties and 70 departments and divisions
- Premises: 734 000 square metres either owned or rented.



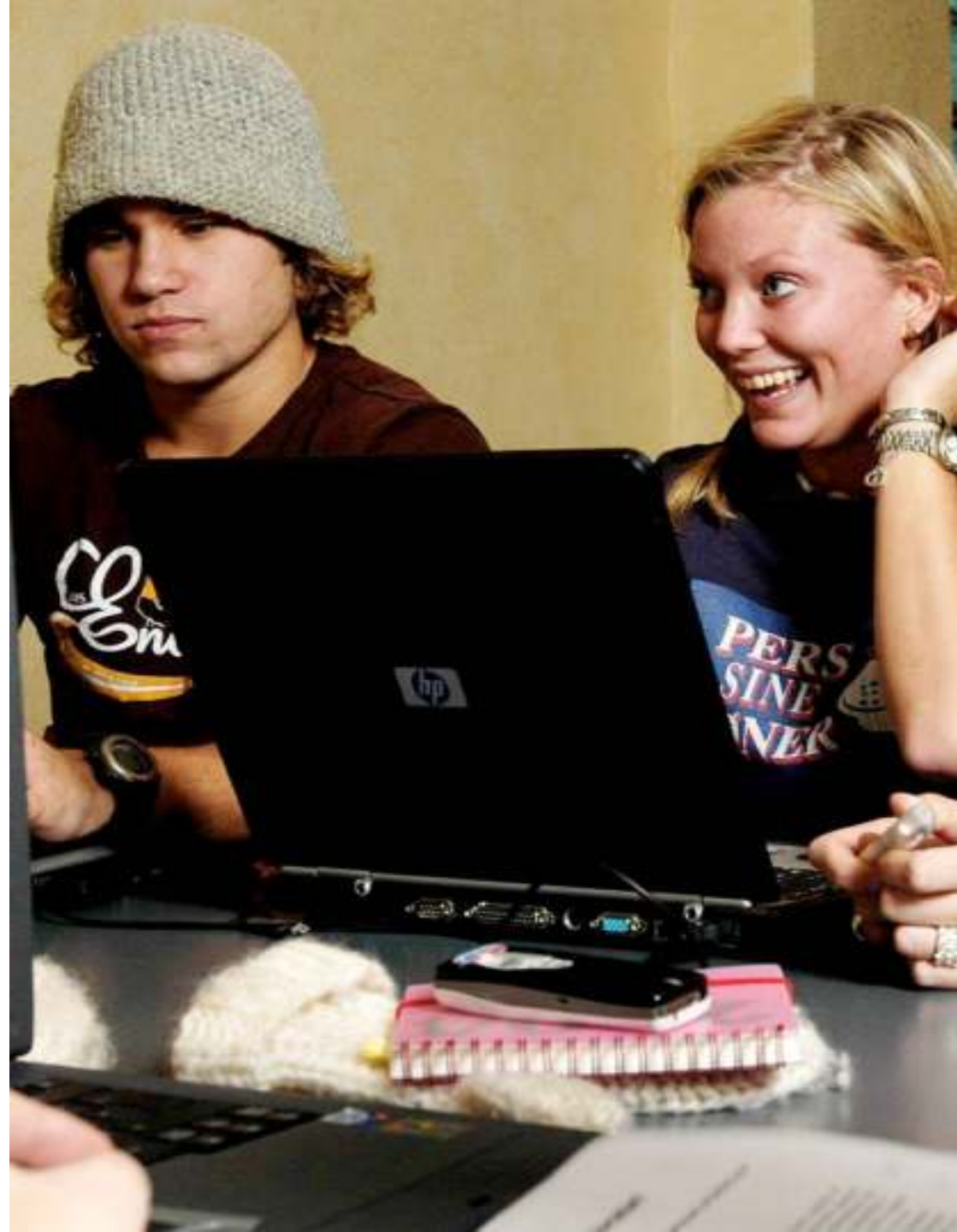
Aurora  
Borealis

Northern Lights



# Studies

- 40 000 students.
- 6553 graduated with a completed degree in 2014.
- 6000 participants in continuing education courses with credit in 2014.
- 3000 international students.
- 340 doctoral degrees awarded in 2015.





# Research and industry partnerships

- PhDs: 340 doctoral degrees awarded in 2015.
- Approximately 120 laboratories.
- Norway's largest participant in the EU's Horizon 2020 (H2020).
- University Library with 17 library branches, 2 million printed books, 950 000 e-books, 16 000 electronic journal subscriptions, 3 000 printed journal subscriptions and 450 databases. More than 3 million downloads of full-text articles.

# STRATEGIC RESEARCH AREAS 2014-2023

 NTNU  
Norwegian University of  
Science and Technology



ENERGY



HEALTH



OCEANS



SUSTAINABILITY

# 2014 Nobel Prize

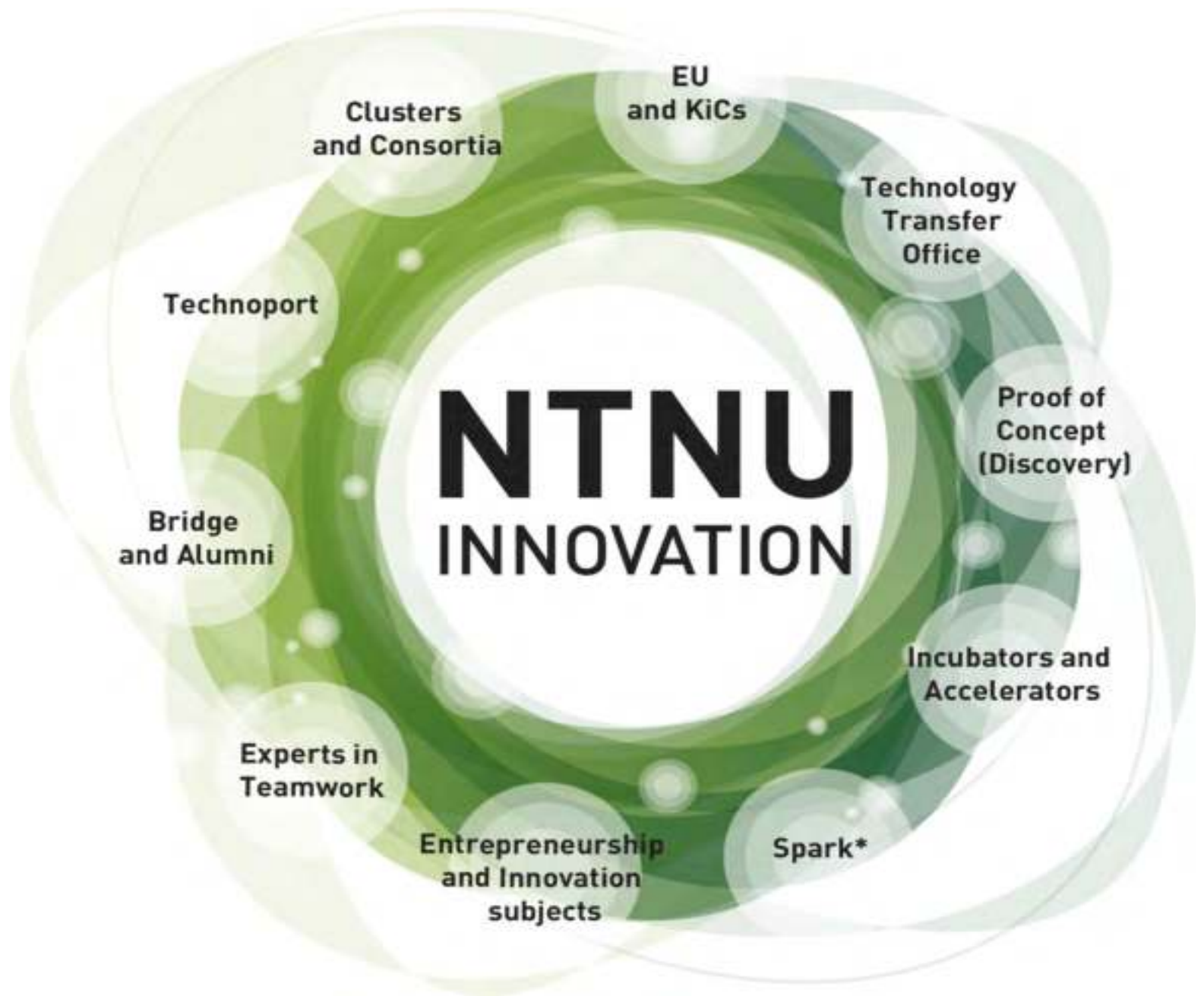
NTNU professors May-Britt Moser and Edvard Moser were awarded the 2014 Nobel Prize in Physiology or Medicine for their discovery of cells that constitute an “inner GPS” in the brain.



# An international university

- Main themes: Europe, China, international mobility, international researcher education.
- Approximately 350 international MoUs for cooperative research and teaching efforts.
- 11 % of NTNU's students are international students.
- 41 % of NTNU's graduated PhDs are international students (2012)
- Students and employees from more than 90 countries.







Clay

Clay

Clay

Clay

Clay

Clay

**Laboratory for Soft and Complex Matter Studies at NTNU, Trondheim, Norway:**

Clay

# Laboratory for Soft and Complex Matter Studies

Home  
People  
Research  
Microfluidics and  
nanofluidics  
Publications  
MSc student projects  
Collaboration  
Teaching  
Events  
News  
Links  
Gallery  
Contact

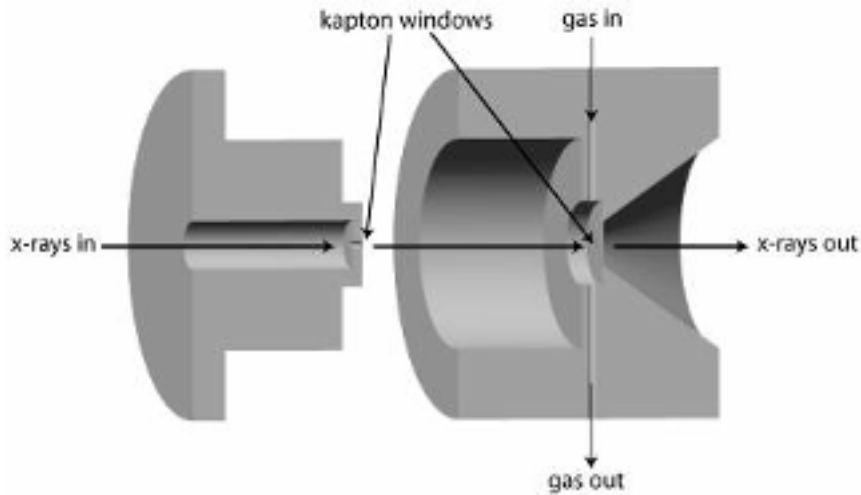
 NTNU  
Norwegian University of  
Science and Technology

<http://folk.ntnu.no/fossumj/lab>

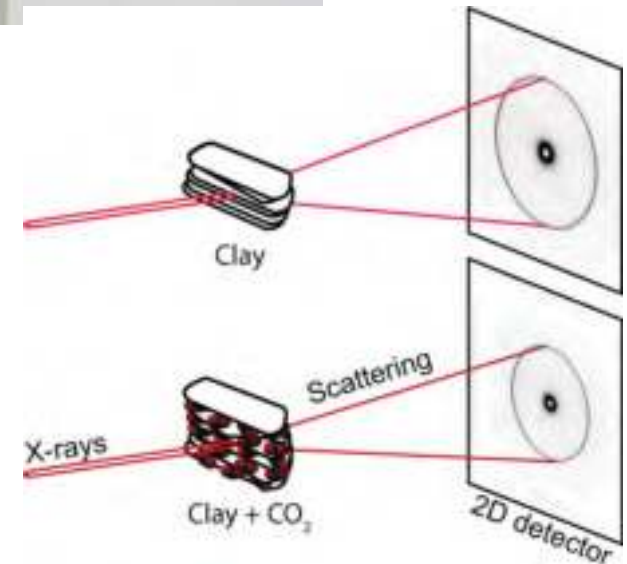
**Our research is focused on probing and understanding how nano-/meso-/micro-structures in complex composites of natural materials manifest themselves in macroscopic material properties and functionalities.**



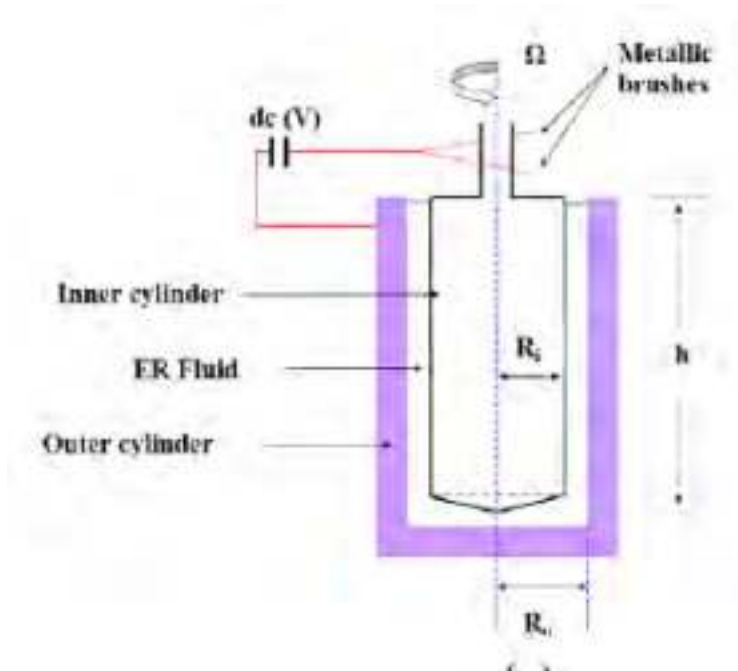
# Nano-scale tools: AFM, Small-Angle X-ray Scattering: SAXS, etc.



Home made sample cell



# Macro-scale tools: Physica MCR 300 Rheometer, etc.





## **Fluid:**

Flows and takes  
shape of container

## **Solid:**

Does not flow and  
keeps its own shape



## **Soft matter:**

**If left alone:**

**Does not flow and  
keeps its own shape**

**If disturbed:**

**Flows and takes desired shape**

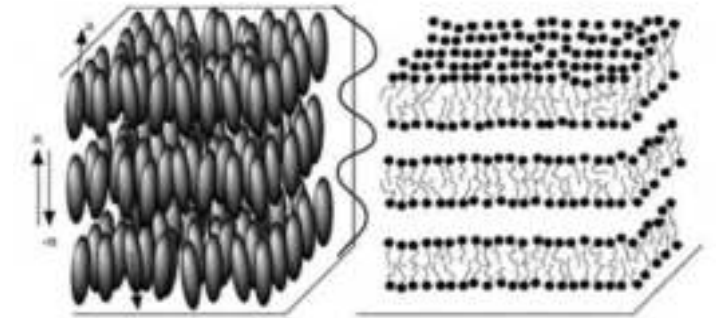
# Soft matter:

Materials which are easily deformable by external stresses, electric or magnetic fields, or even by thermal fluctuations.



Soft materials are typically shear-thinning, i.e. they possess a yield stress below which they are elastic materials, and above which they are viscous.

**These materials typically possess structures on the nanoscale; the structure and dynamics at nano-/meso-scopic scales determine the physical properties of these materials.**



The goal of soft matter research is to probe and understand how nano-/meso-structures translate into macroscopic properties and behaviors.

**Researchers study natural, synthetic and biological materials in this context.**

Interests extend from fundamental physics to technological applications, from basic materials questions to specific biological problems = Multidisciplinary field.

**The tools used include light, X-ray, neutron scattering, microscopy, rheometry, microfluidics, special purpose table-top experiments, numerics, theory.**

**The founder of soft matter science:**

**Pierre-Gilles de Gennes**

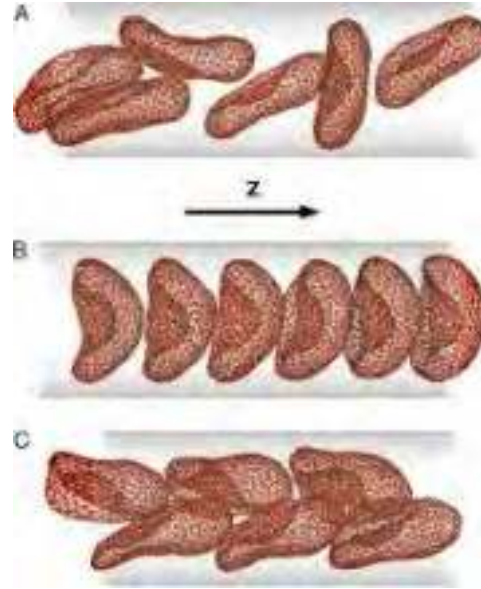
French physicist : 1932 –2007,  
Nobel Prize laureate in physics in 1991



# Food is Soft Matter

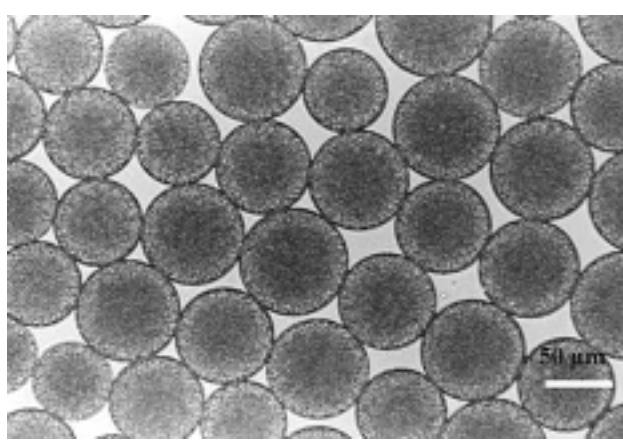


# Biomatter is Soft Matter



Cell elasticity and deformation  
in flow





# Designer emulsions using microfluidics

## Monodisperse Emulsions

The study of drops of one fluid in an immiscible fluid

We describe new developments for the controlled fabrication of monodisperse emulsions using microfluidics. We use glass capillary devices to generate single, double, and higher order emulsions with exceptional precision. These emulsions can serve as ideal templates for generating well-defined particles and functional vesicles. Polydimethylsiloxane microfluidic devices are also used to generate picoliter-scale water-in-oil emulsions at rates as high as 10 000 drops per second. These emulsions have great potential as individual microvessels in high-throughput screening applications, where each drop serves to encapsulate single cells, genes, or reactants.

Rhutesh K. Shah<sup>a</sup>, Ho Cheung Shum<sup>a</sup>, Amy C. Rowat<sup>a</sup>, Daeyeon Lee<sup>a</sup>, Jeremy J. Agresti<sup>a</sup>, Andrew S. Utada<sup>a</sup>, Liang-Yin Chu<sup>a,b</sup>, Jin-Woong Kim<sup>a,c</sup>, Alberto Fernandez-Nieves<sup>a,d</sup>, Carlos J. Martinez<sup>a,e</sup>, and David A. Weitz<sup>a,f\*</sup>

<sup>a</sup>School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA

<sup>b</sup>School of Chemical Engineering, Sichuan University, Chengdu, Sichuan, 610065, China

<sup>c</sup>Amore-Pacific R&D Center, 314-1, Bora-dong, Giheung-gu, Yongin-si, Gyeonggi-Do, 446-729, Korea

<sup>d</sup>School of Physics, Georgia Institute of Technology, Atlanta, GA 30332, USA

<sup>e</sup>School of Materials Engineering, Purdue University, West Lafayette, IN 47907, USA

<sup>f</sup>Department of Physics, Harvard University, Cambridge, MA 02138, USA

\*E-mail: [weitz@seas.harvard.edu](mailto:weitz@seas.harvard.edu)



# Monodisperse emulsions

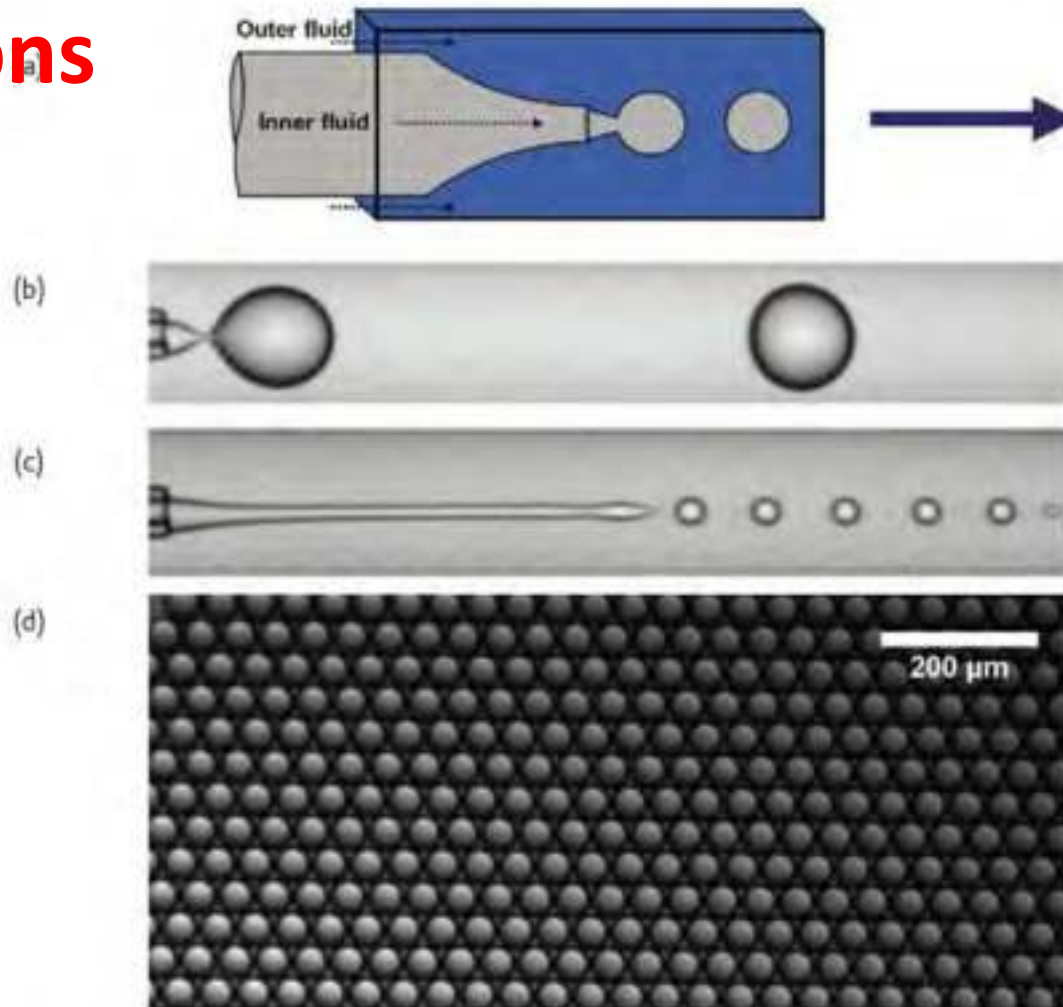
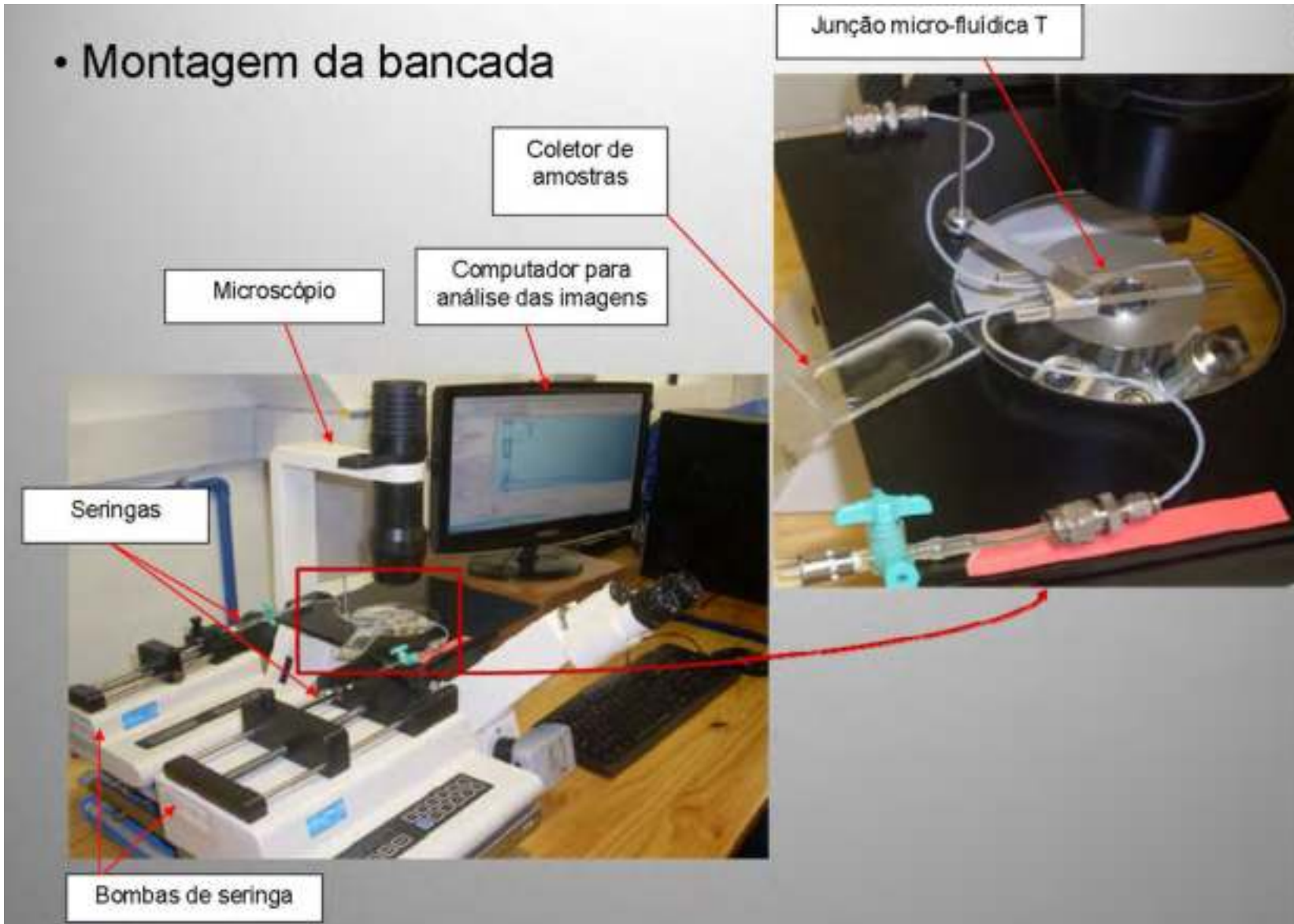
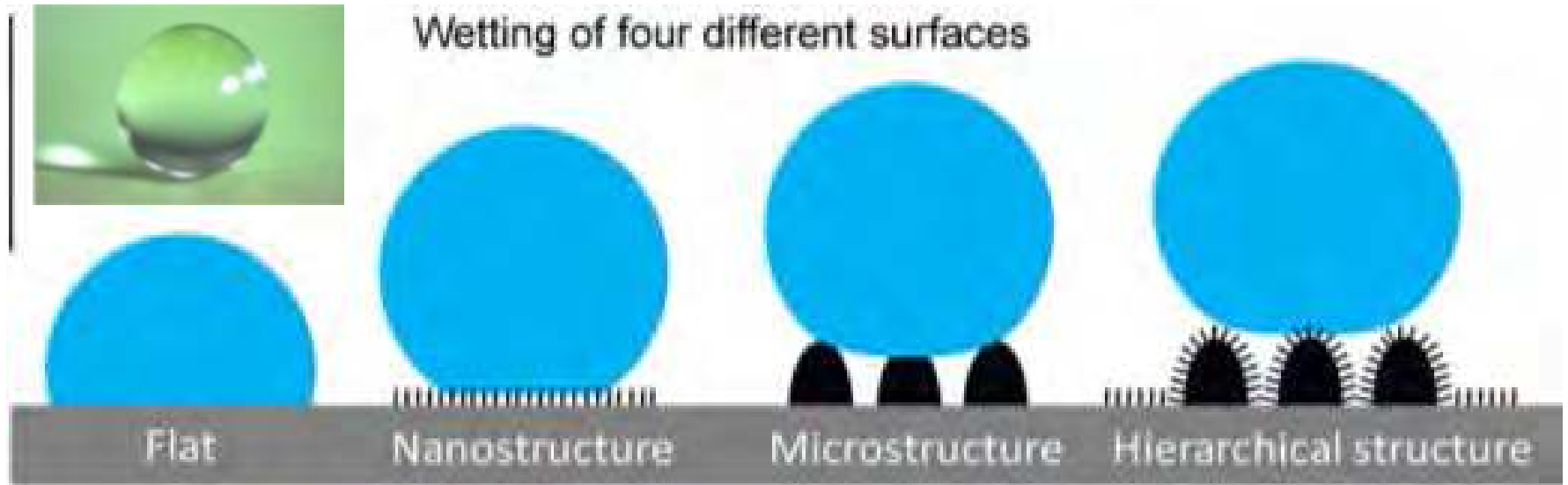


Fig. 2 Single emulsions in a co-flow microfluidic device. (a) Schematic of a co-flow microcapillary device for making droplets. Arrows indicate the flow direction of fluids and drops. (b) Image of drop formation at low flow rates (dripping regime). (c) Image of a narrowing jet generated by increasing the flow rate of the continuous fluid above a threshold value while keeping the flow rate of the dispersed phase constant. (d) Monodisperse droplets formed using a microcapillary device. [Part (a) reproduced with permission from<sup>26</sup>. © 2007 Materials Research Society; parts (b) and (c) reprinted with permission from<sup>27</sup>. © 2007 American Physical Society.]

# Table-top experiment:

- Montagem da bancada





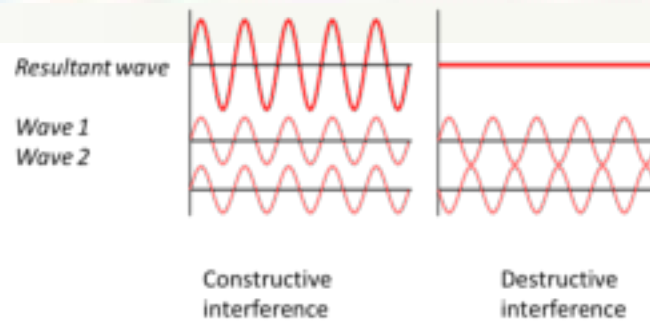
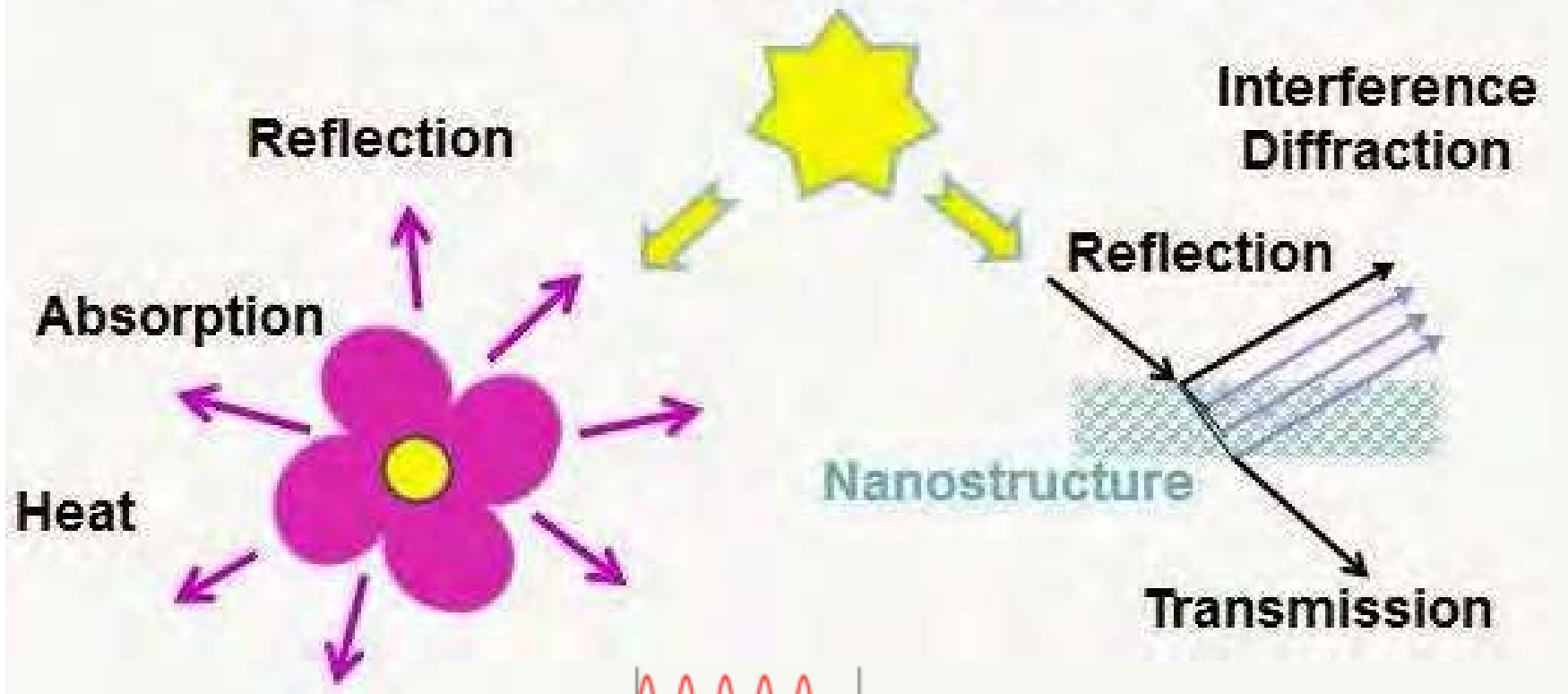
Schematics of wetting of four different surfaces. The largest contact area between the droplet and the surface is given in flat and micro-structured surfaces, is reduced in nano-structured surfaces, and is minimized in hierarchical (nano-micro) structured surfaces. This contains the principle of the so-called self-cleaning Lotus leaf effect, depicted to the left.

*Natural and biomimetic artificial surfaces for super-hydrophobicity, self-cleaning, low adhesion, and drag reduction*, B. Bhushan, Y. C. Jung, *Progress in Materials Science* 56, 1-108 (2011)

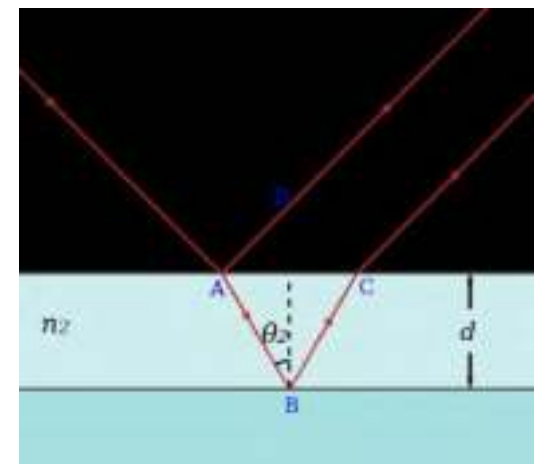


Peacock feathers: Brown pigment + nanostructures

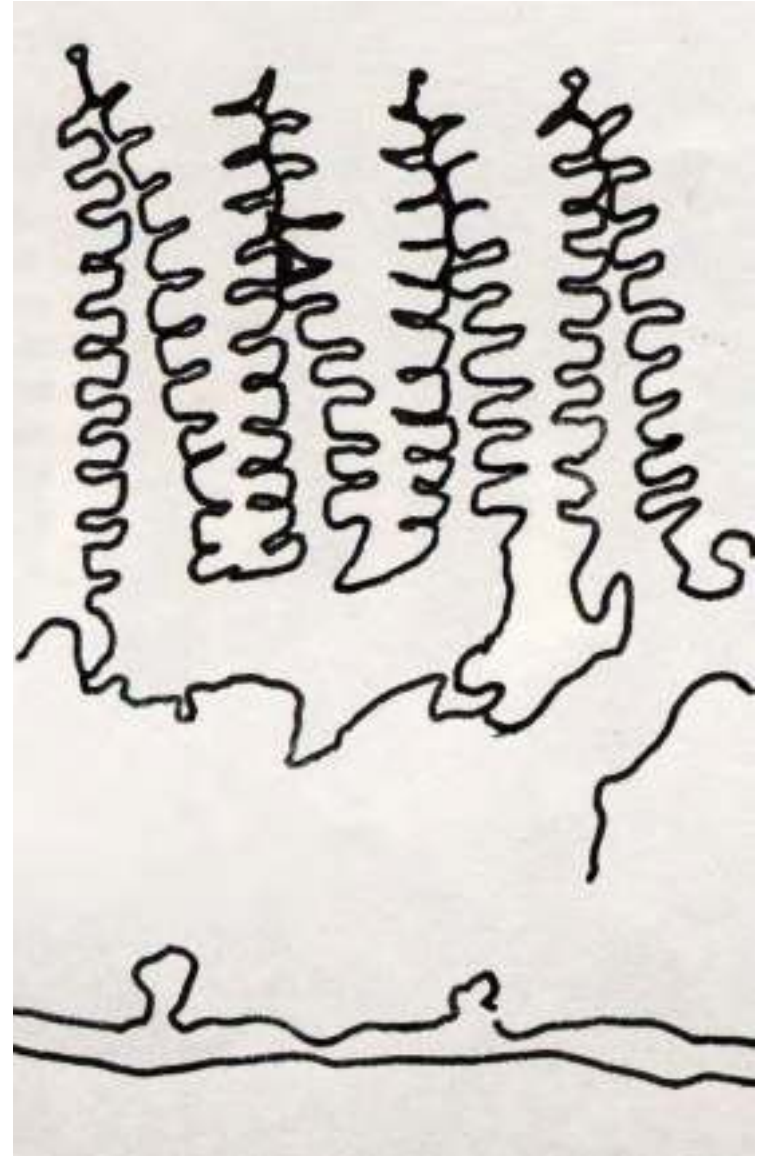
# Pigmentary Color vs. Structural Color



When light falls on a thin film, the waves reflected from the upper and lower surfaces travel different distances depending on the angle, so they interfere.



Butterfly wing at different magnifications reveals mesostructured chitin acting as a diffraction grating

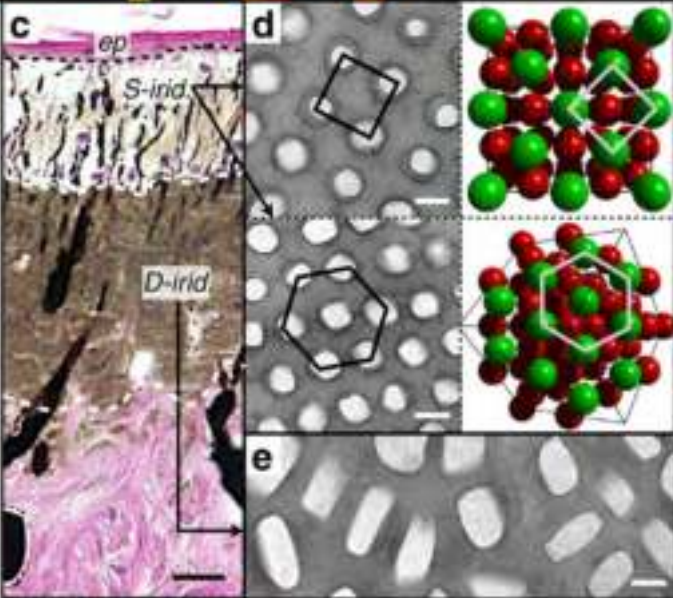
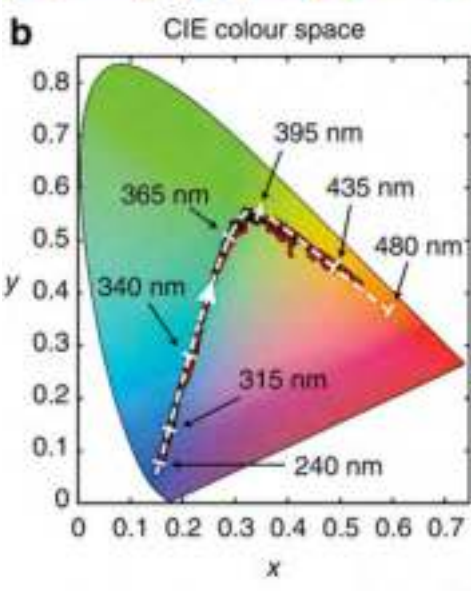
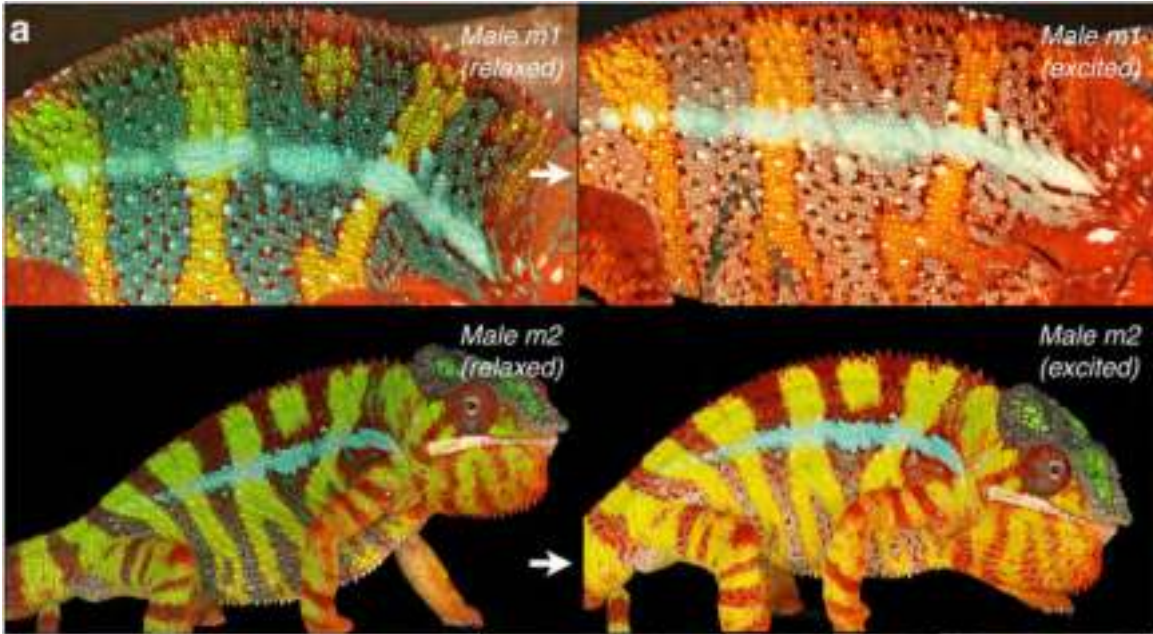


# Photonic crystals cause active colour change in chameleons

J r mie Teys cier, Suzanne V. Saenko, Dirk van der Marel & Michel C. Milinkovitch

Nature Communications 6,  
Article number: 6368 (2015)  
doi:10.1038/ncomms7368  
Download Citation  
Photonic crystals

Received: 16 June 2014  
Accepted: 22 January 2015  
Published online: 10 March 2015



Chameleons can change their color in less than 1 second

## Examples from wikipedia:



European bee-eaters owe their brilliant colours partly to diffraction grating microstructures in their feathers

In Morpho butterflies such as *Morpho helena* the brilliant colours are produced by intricate fir-tree-shaped microstructures too small for optical microscopes.

The male *Parotia lawesii* bird of paradise signals to the female with his breast feathers that switch from blue to yellow.

Brilliant green of emerald swallowtail, *Papilio palinurus*, is created by arrays of microscopic bowls that reflect yellow directly and blue from the sides.

Emerald-patched cattleheart butterfly, *Parides sesostris*, creates its brilliant green using photonic crystals.

Iridescent scales of *Lamprocyphus augustus* weevil contain diamond-based crystal lattices oriented in all directions to give almost uniform green.

Hollow nanofibre bristles of *Aphrodita aculeata* (a species of sea mouse) reflect light in yellows, reds and greens to warn off predators.



Longfin inshore squid, *Doryteuthis pealeii*, has been studied for its ability to change colour.

Thin-film interference in a soap bubble. Colour varies with film thickness.

Smoked pork loin showing iridescence due to the fine arrangement of the muscle fibrils.



# Full-Color Biomimetic Photonic Materials with Iridescent and Non-Iridescent Structural Colors

Ayaka Kawamura, Michinari Kohri, Gen Morimoto, Yuri Nannichi, Tatsuo Taniguchi & Keiki Kishikawa

Scientific Reports 6,

Article number: 33984 (2016)

doi:10.1038/srep33984

Download Citation:

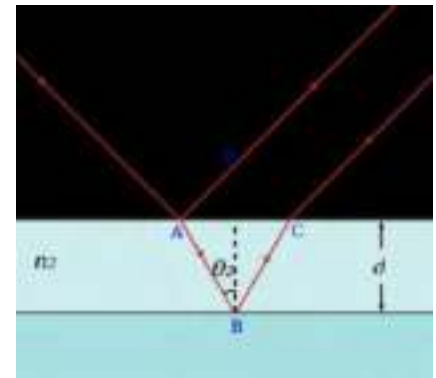
Materials for optics

Optical materials

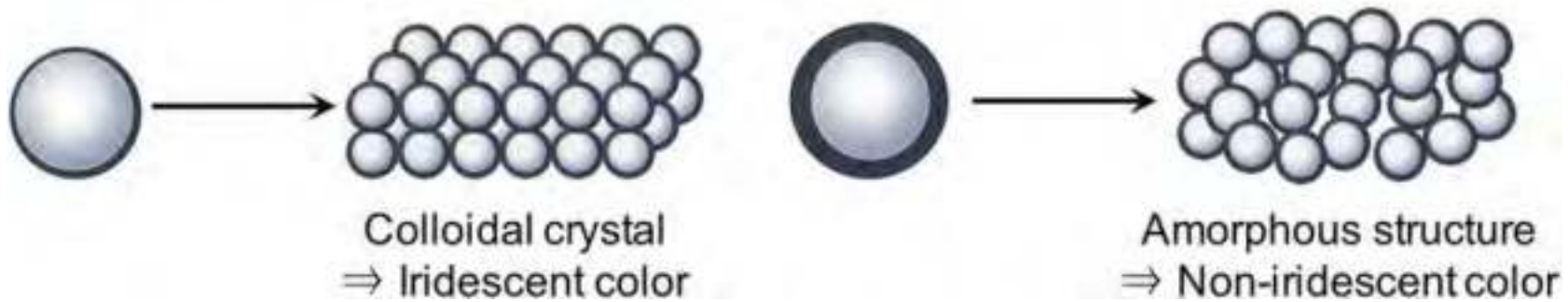
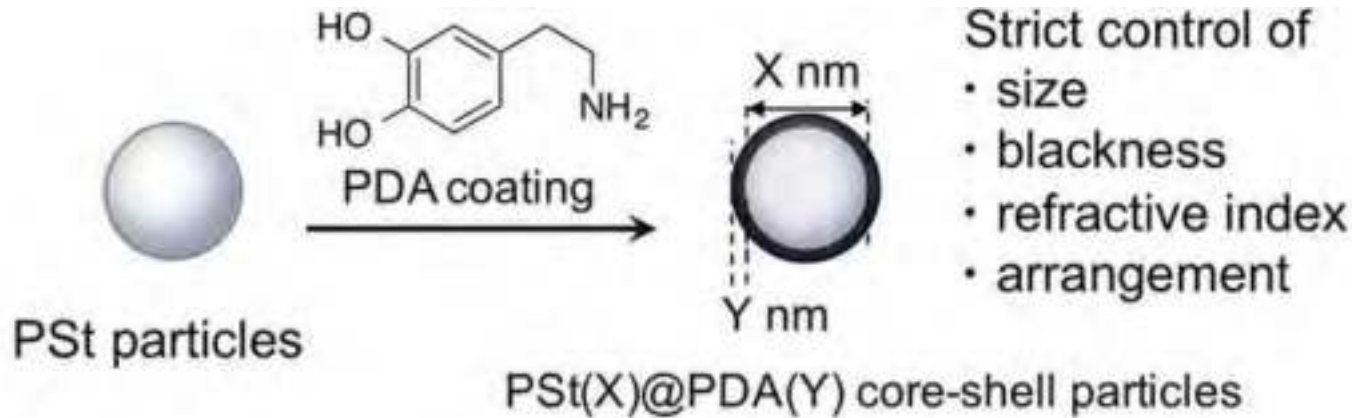
Received: 04 August 2016

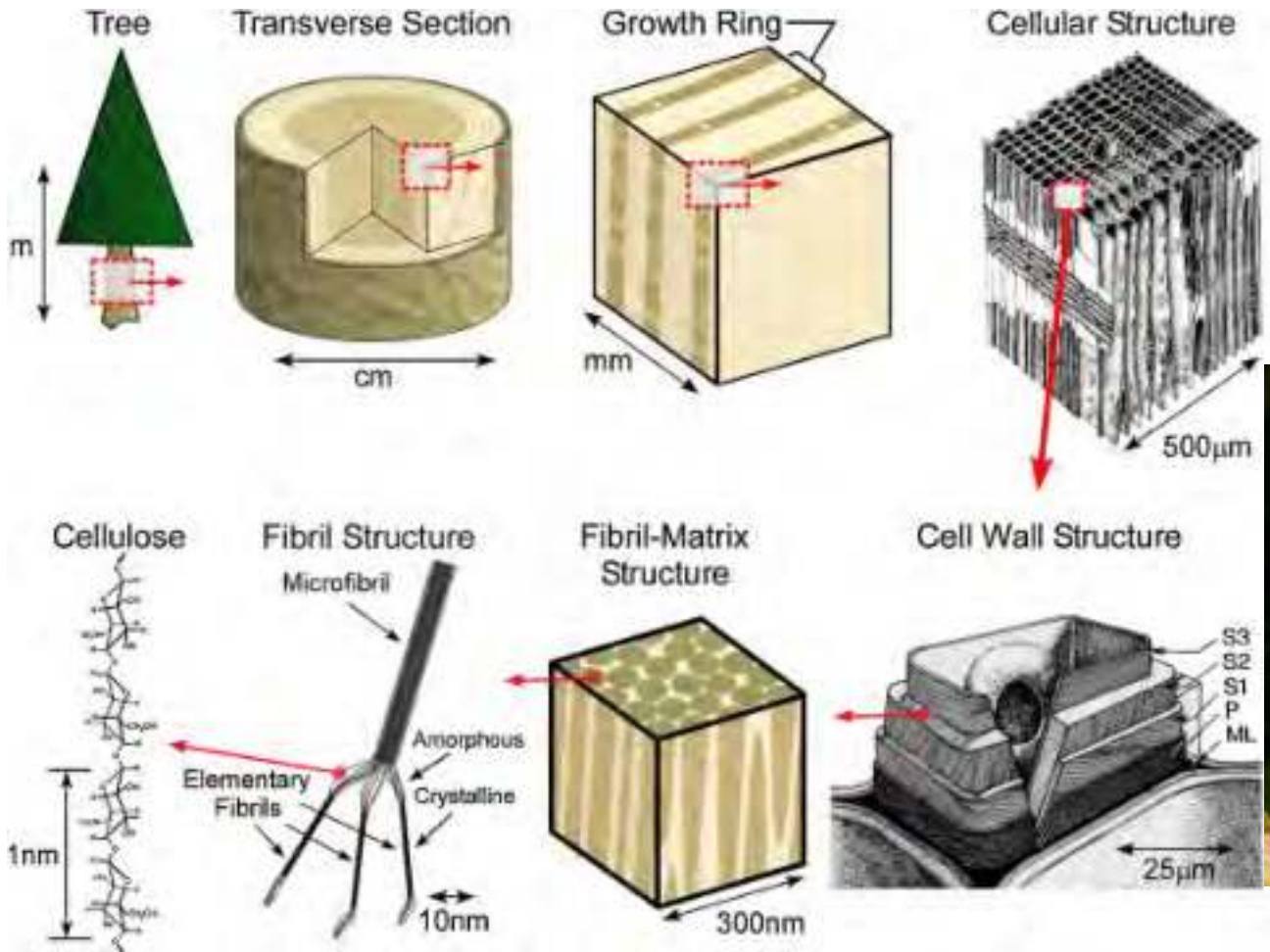
Accepted: 06 September 2016

Published online: 23 September 2016

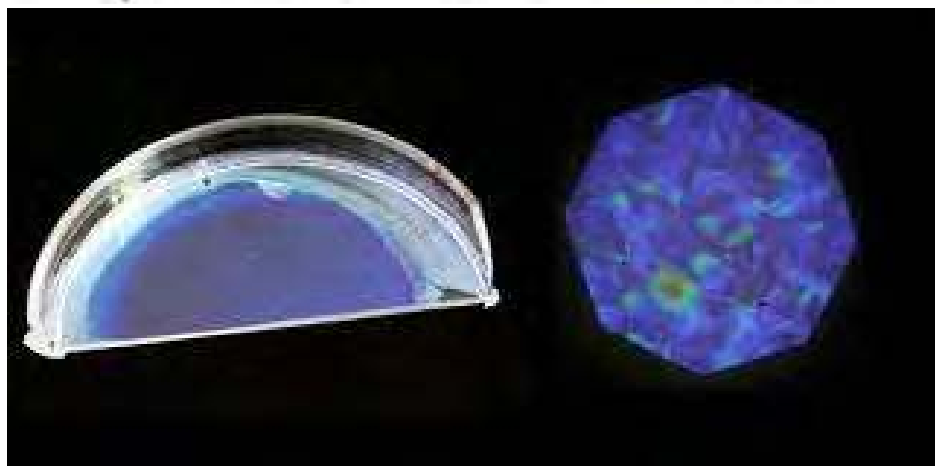


Polydopamine (PDA) shell layers  
+ core polystyrene (PSt) particles

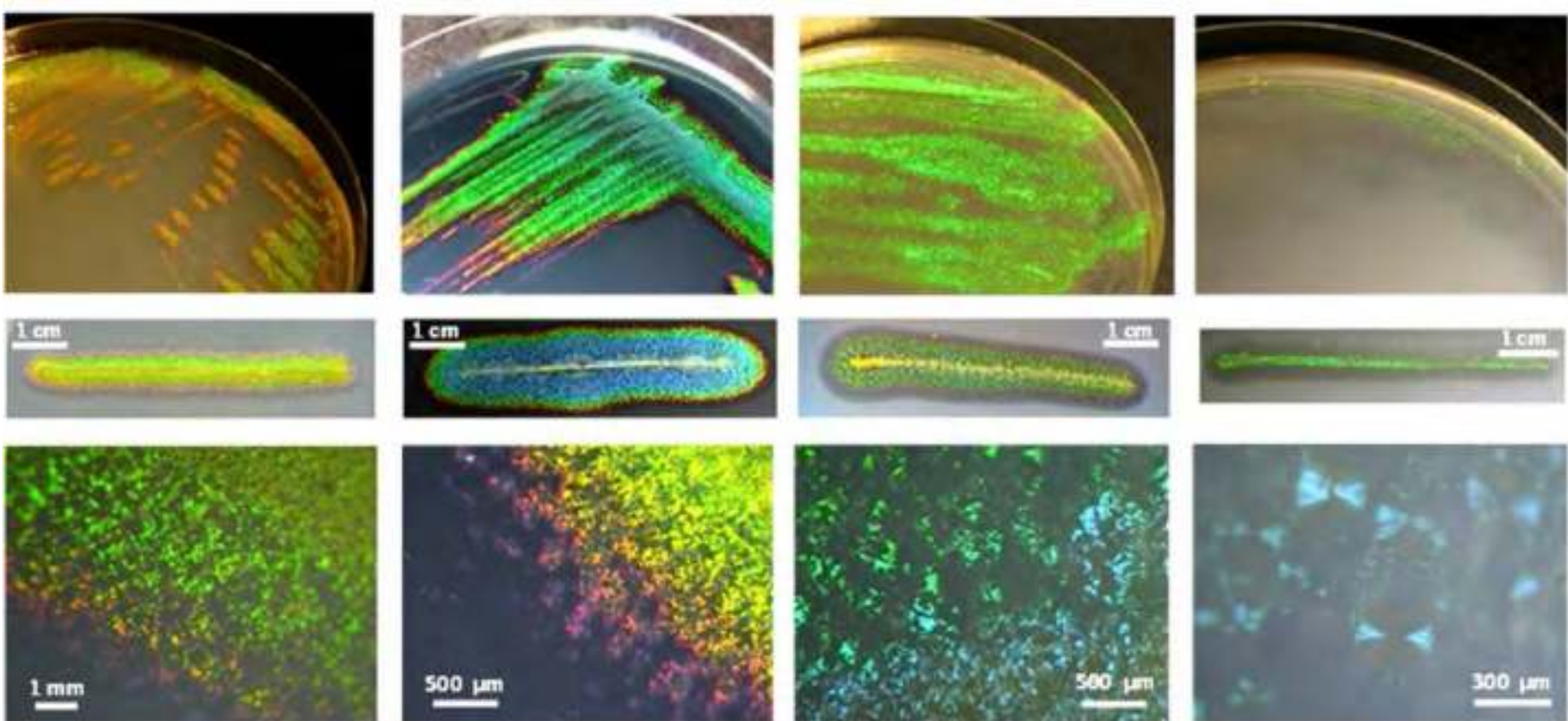




The most intense blue known in nature: African *Pollia condensata* berries



Dumanli, A. G., Kamita, G., Landman, J., van der Kooij, H., Glover, B. J., Baumberg, J. J., Steiner, U. and Vignolini, S. (2014), "Controlled, Bio-inspired Self-Assembly of Cellulose-Based Chiral Reflectors." *Advanced Optical Materials*. doi: 10.1002/adom.201400112



# SCIENTIFIC REPORTS

OPEN

## A unique self-organization of bacterial sub-communities creates iridescence in *Cellulophaga lytica* colony biofilms

Betty Kientz<sup>1,4</sup>, Stephen Luke<sup>2</sup>, Peter Vukusic<sup>2,4</sup>, Renaud Péteri<sup>3,4</sup>, Cyrille Beaudry<sup>3</sup>, Tristan Renault<sup>4</sup>, David Simon<sup>3</sup>, Tām Mignot<sup>5</sup> & Eric Rosenfeld<sup>2,4</sup>

Received: 30 July 2015

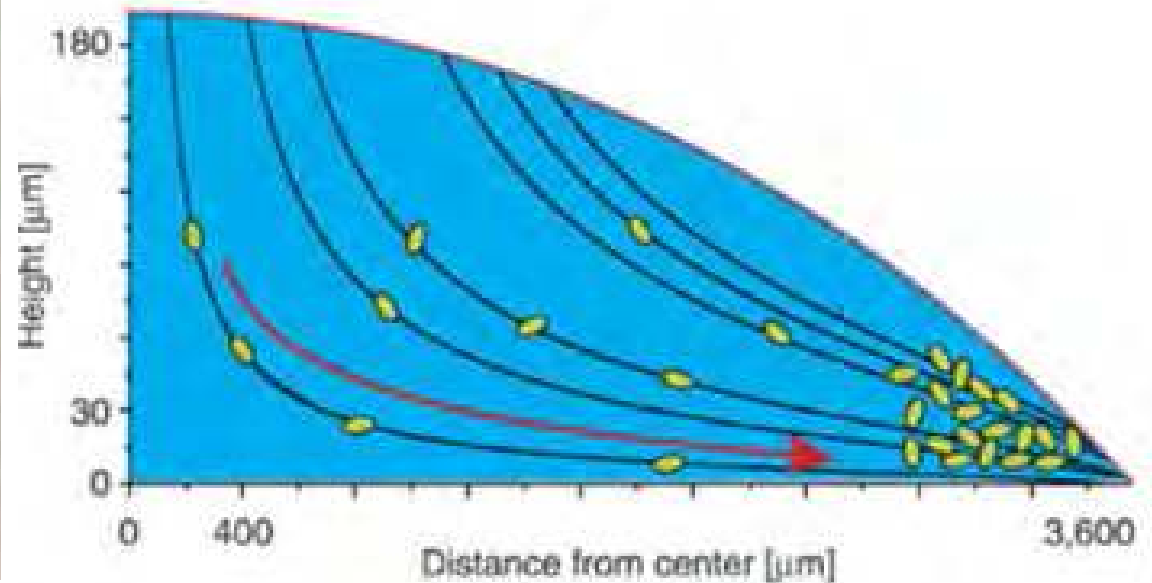
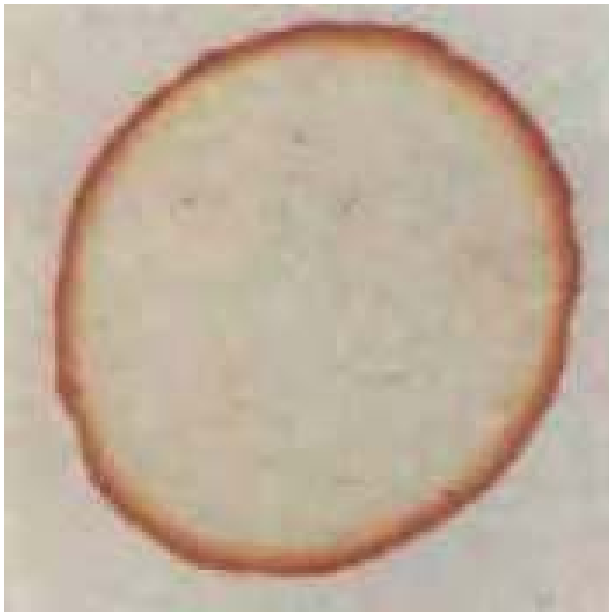
Accepted: 17 December 2015

Published: 28 January 2016

# Self-assembly:

Making a macroscopic sample (i.e. about  $10^{20}$  nanoparticles) by physically picking up and moving nanoparticles into place, one by one, would take about 300 million years, even if the time for moving individual particles could be made as short as 1 millisecond.

One of many examples of self-assembly: The coffee stain effect:





**Self-assembly:**

**Emergent patterns, more is different**

**Human made design:  
Top-down assembly**



**How nature works:  
Bottom-up Self-assembly**



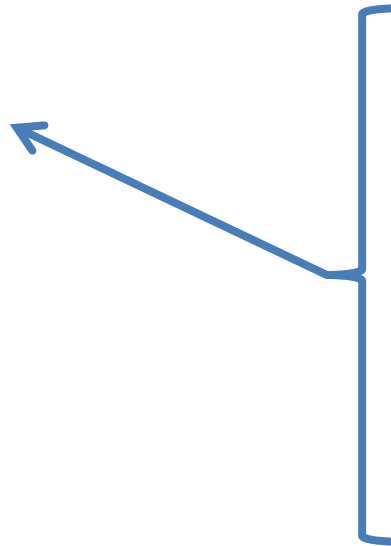
**Scientific challenge of nanostructured self-assembly:  
Combination of Top-down and Bottom-up:**



Another pile of rocks

# Example of self-organization: Liquid Crystalline Phases

Order Parameter = O.P.  
= Angular distribution function  
 $= S_2 = \frac{1}{2} \langle 3 \cos^2 \theta - 1 \rangle$



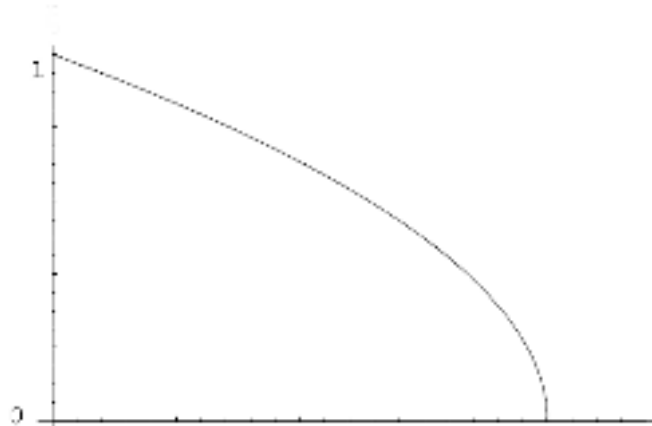
Isotropic Phase  
(O.P. = 0) :  
No orientational order,  
no positional order



Nematic Phase  
(O.P.  $\neq 0$ ):  
Orientational order,  
no positional order



Order Parameter  
( $0 < \text{O.P.} < 1$ ) = Angular  
distribution function



Particle concentration, Electric fields, Magnetic fields, Etc.



Flocking and swarming





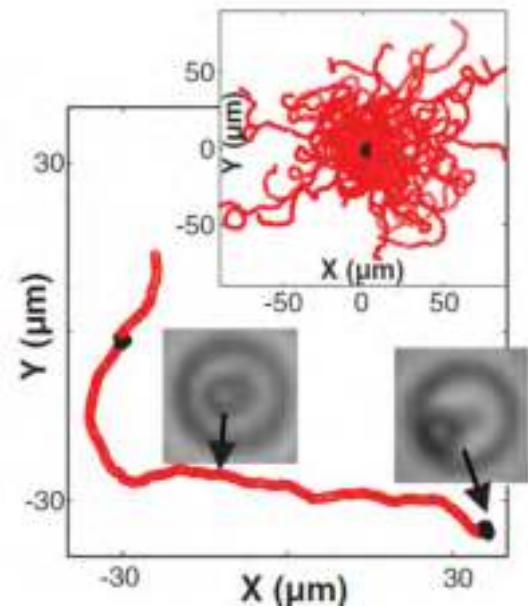
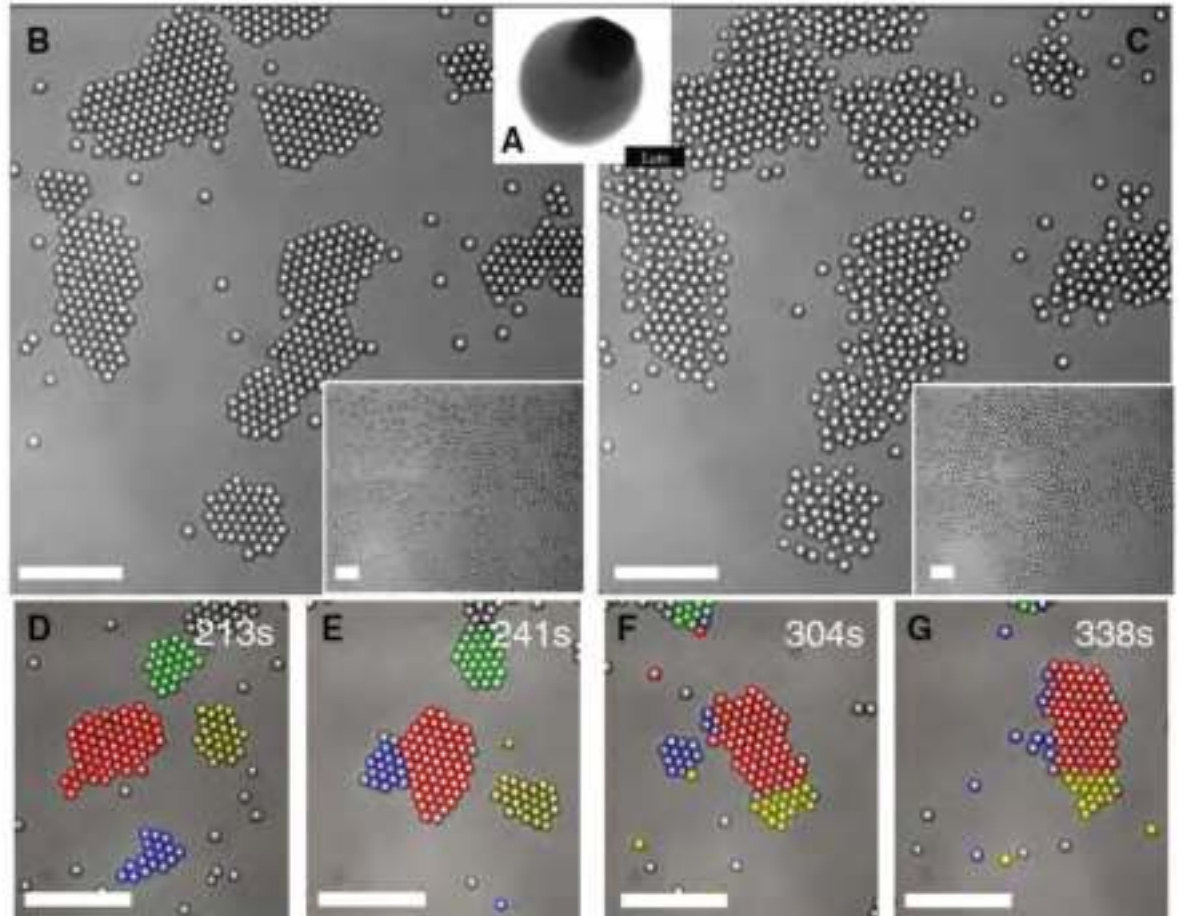
## Fluid Dynamics of Bacterial Turbulence

Jörn Dunkel,<sup>1</sup> Sebastian Heidenreich,<sup>2</sup> Knut Drescher,<sup>3</sup> Henricus H. Wensink,<sup>4</sup> Markus Bär,<sup>2</sup> and Raymond E. Goldstein<sup>1</sup>

[exp\\_03\\_40xoil\\_40fps\\_fluo.mov](#): Real-time low-resolution movie (duration 50 s) of tracer motion as used for the PTV analysis (see main text for imaging parameters).

[exp\\_03.mov](#): Real-time movie (duration 50 s) of the PIV flow field as extracted from "[exp\\_03\\_40xoil\\_40fps\\_brightfield.mov](#)".

**Fig. 1.** (A) Scanning electron microscopy (SEM) of the bimaterial colloid: a TPM polymer colloidal sphere with protruding hematite cube (dark). (B) Living crystals assembled from a homogeneous distribution (inset) under illumination by blue light. (C) Living crystals melt by thermal diffusion when light is extinguished: Image shows system 10 s after blue light is turned off (inset, after 100 s). (D to G) The false colors show the time evolution of particles belonging to different clusters. The clusters are not static but rearrange, exchange particles, merge (D→F), break apart (E→F), or become unstable and explode (blue cluster, F→G). For (B) to (G), the scale bars indicate 10  $\mu\text{m}$ . The solid area fraction is  $\Phi_s \approx 0.14$ .



A hematite cube protruding from a TPM polymer sphere moves on fixed glass substrate when exposed to blue light (red part of trace) and diffuses when the light is off (black part of trace). Initially, with no light, the hematite cube is oriented randomly (image, right) but rotates and faces downward toward the glass substrate when the light is turned on (image, left). The particle then surfs on the osmotic flow it induces between the substrate and itself. (Inset) A superposition of the trajectories of many particles with their origins aligned.



## Living Crystals of Light-Activated Colloidal Surfers

Jeremie Palacci *et al.*

*Science* **339**, 936 (2013);

DOI: [10.1126/science.1230020](https://doi.org/10.1126/science.1230020)

Phoretic and osmotic effects can conveniently be switched on and off by light.

1896.

ANNALEN

DE 19.

PHYSIK UND CHEMIE.

NEUE FOLGE. BAND 59.

1) *Ueber Rotationen im uniaxialen elektrischen Felde*; von G. Quincke.

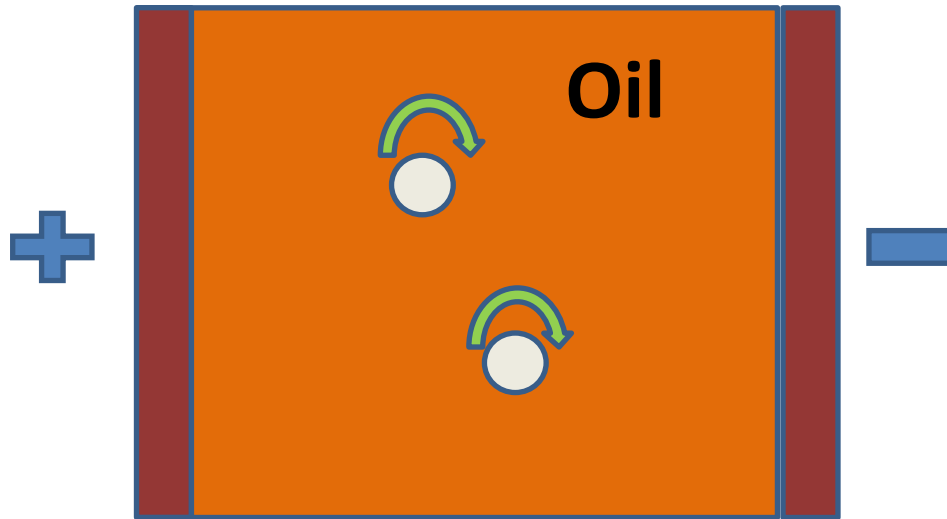
[Utrecht, Taf. 7, S. 57, Fig. 1—24.]

Georg Hermann Quincke



<b>Born</b>	19 November 1834 Frankfurt (Oder)
<b>Died</b>	13 January 1924 (aged 89) Heidelberg
<b>Nationality</b>	German
<b>Fields</b>	Physics
<b>Doctoral advisor</b>	H. G. Magnus, F. E. Neumann
<b>Doctoral students</b>	K. F. Braun, P. Lenard

Quincke rotation



**Small glass beads rotate spontaneously when immersed in liquids and subject to an electrostatic field**

1. Threshold electric field
2. Rotation axis normal to the applied E-field

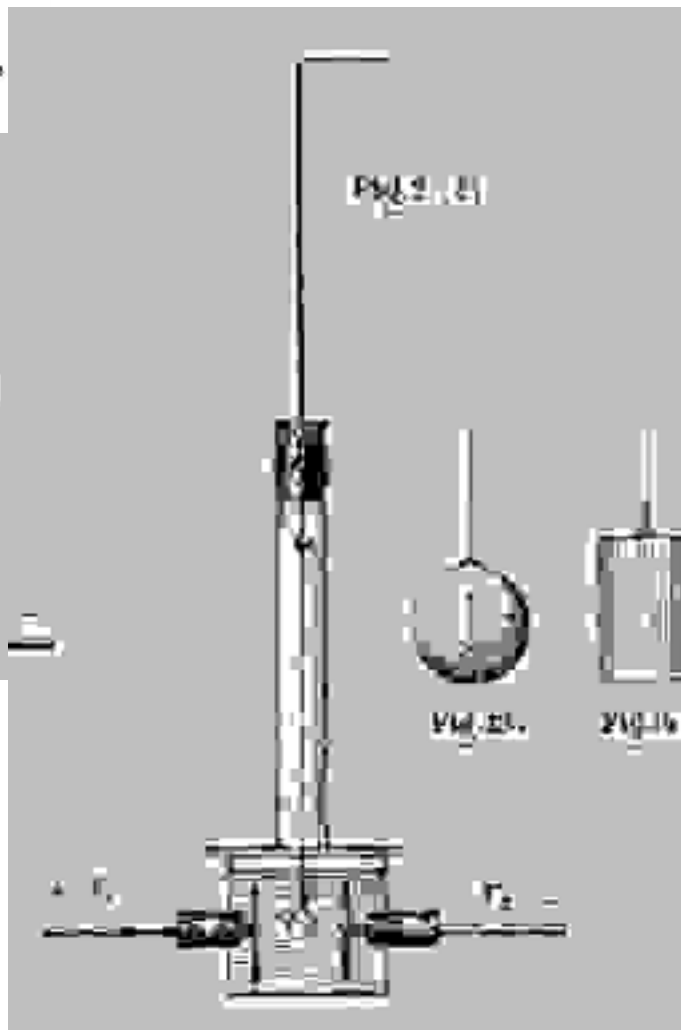
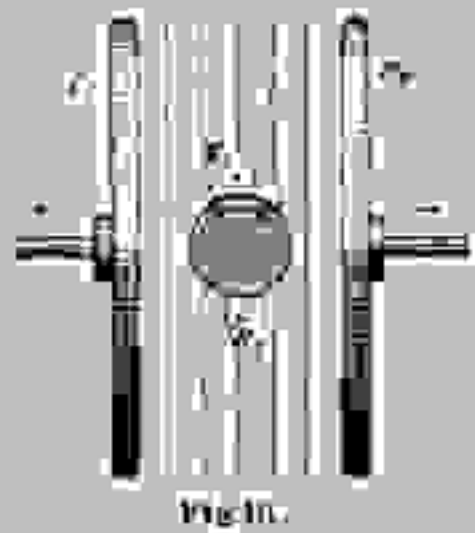
# Quincke rotation

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Ueber Rotationen im constanten electrischen Felde von G. Quincke \*)  
(Annalen P. 6, 51, 10. 1-85)



## Georg Hermann Quincke



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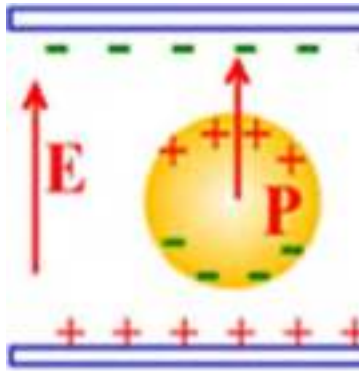
# Quincke rotation

# Quincke Rotation: Dynamic dipole instability

$$\tau_{fluid} = \frac{\epsilon_{fluid}}{\sigma_{fluid}}$$

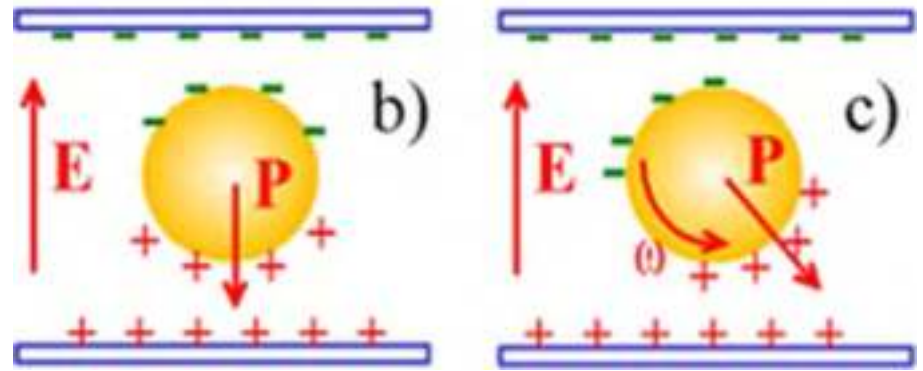
$$\tau_{particle} = \frac{\epsilon_{particle}}{\sigma_{particle}}$$

$\tau_{fluid} > \tau_{particle}$



**Polarization is parallel with the applied field**

$\tau_{fluid} < \tau_{particle}$



**Polarization is anti-parallel with the applied field, Unstable dipole.**

# Electrohydrodynamic interaction of spherical particles under Quincke rotation

Debasish Das and David Saintillan\*

*Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA*

(Received 3 March 2013; published 29 April 2013)

$$\Omega = \pm \frac{1}{\tau_{\text{MW}}} \sqrt{\left(\frac{E_e}{E_c}\right)^2 - 1}, \quad \text{with}$$

$$E_c = \sqrt{\frac{2\eta}{\varepsilon_1 \tau_{\text{MW}}(\varepsilon_{21} - \sigma_{21})}}.$$

No radius dependence !

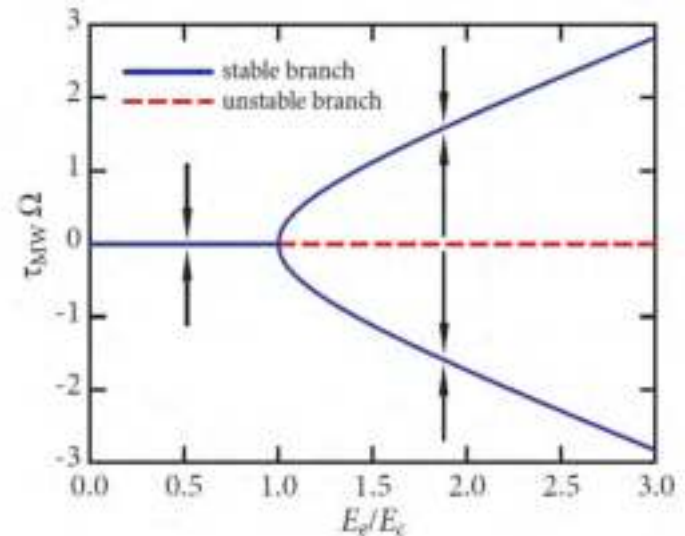
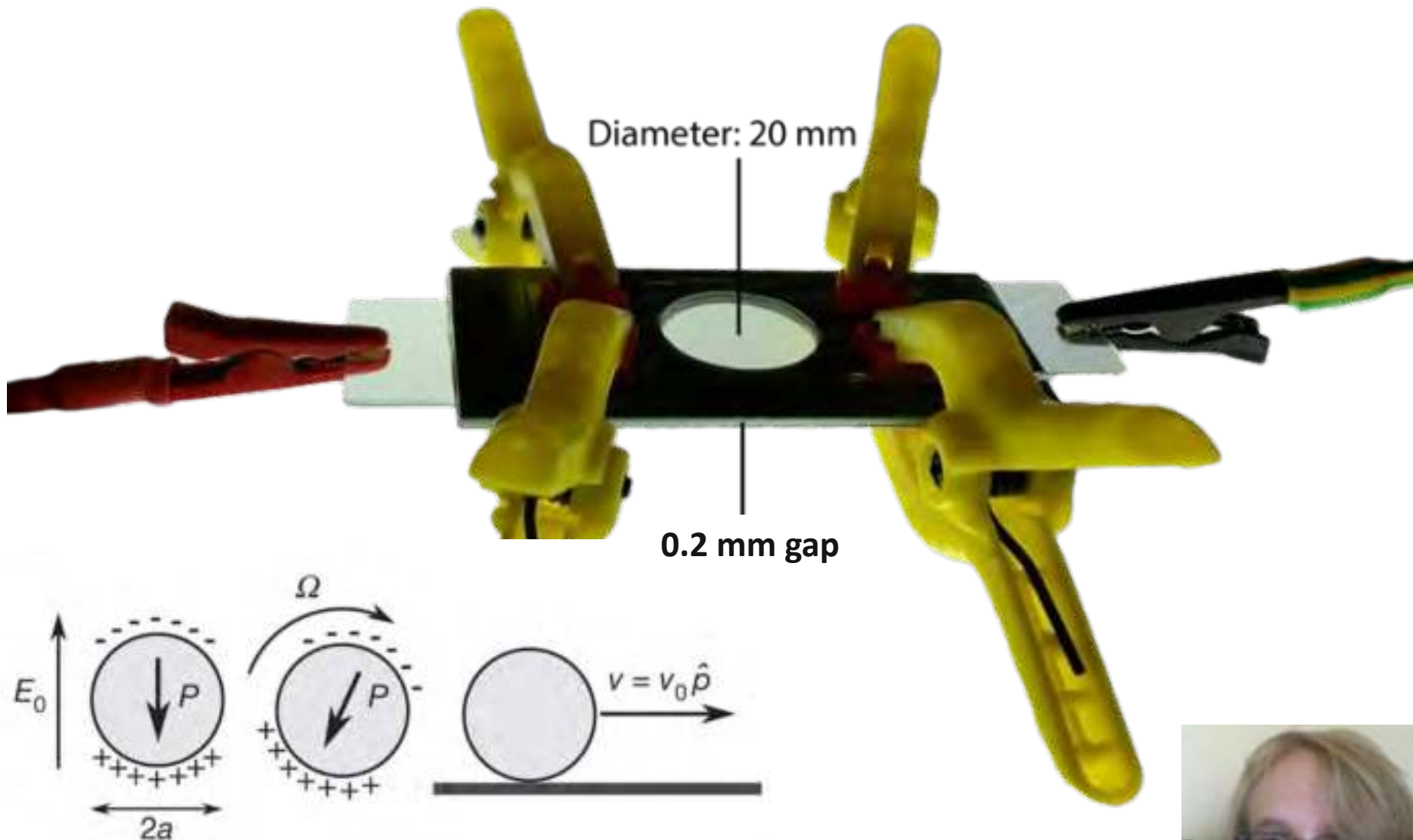


FIG. 3. (Color online) Stability diagram for the angular velocity magnitude of a single sphere. A supercritical pitchfork bifurcation occurs at  $E_e = E_c$ ; above this value, the solution  $\Omega = 0$  becomes unstable and spontaneous rotation occurs with an angular velocity given by Eq. (33).



Hele-Shaw cell with ITO glass covers: suspension containing 30micron PS beads



Experiments at NTNU Trondheim: Tommy Kristiansen



40 $\mu$ m 2250V/mm

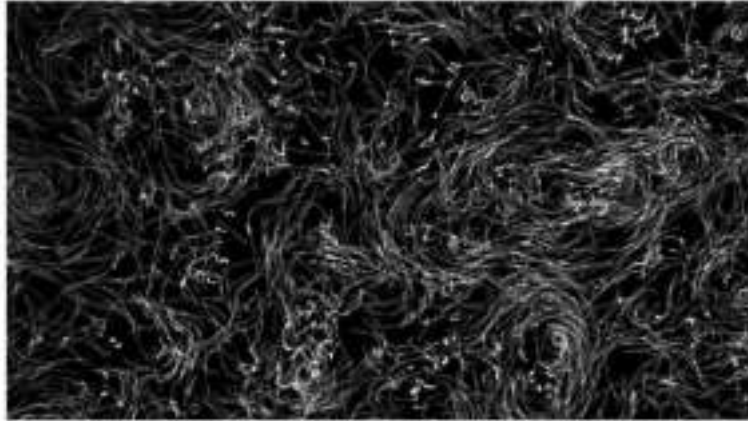
Fast moving quincke rollers

Experiments at NTNU Trondheim: Tommy Kristiansen

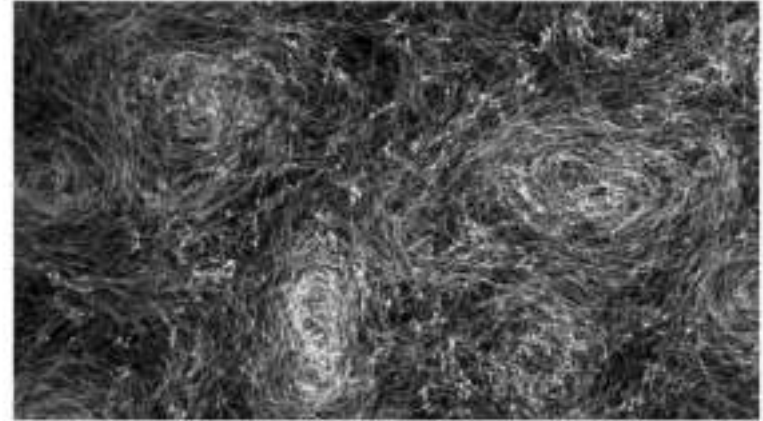


Streak photography night sky

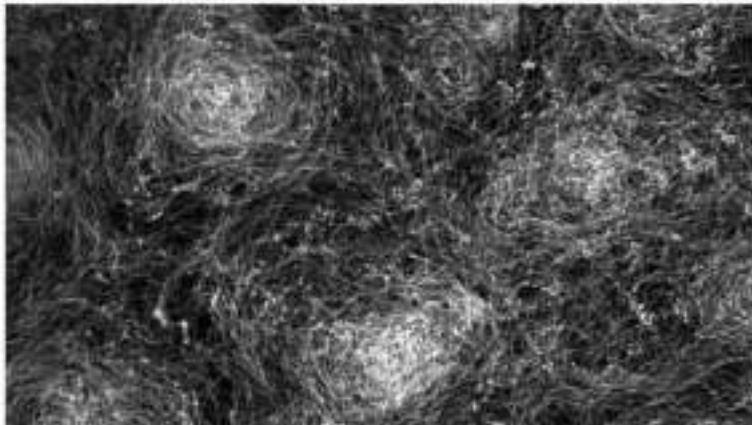
# Streak photos of fast moving Quincke rollers: «Vortices»



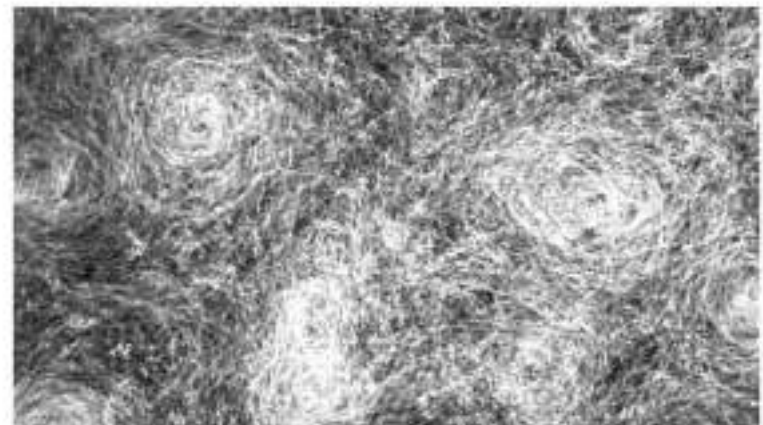
15 frames after 0 secs



100 frames after 3 secs



100 frames after 6 secs

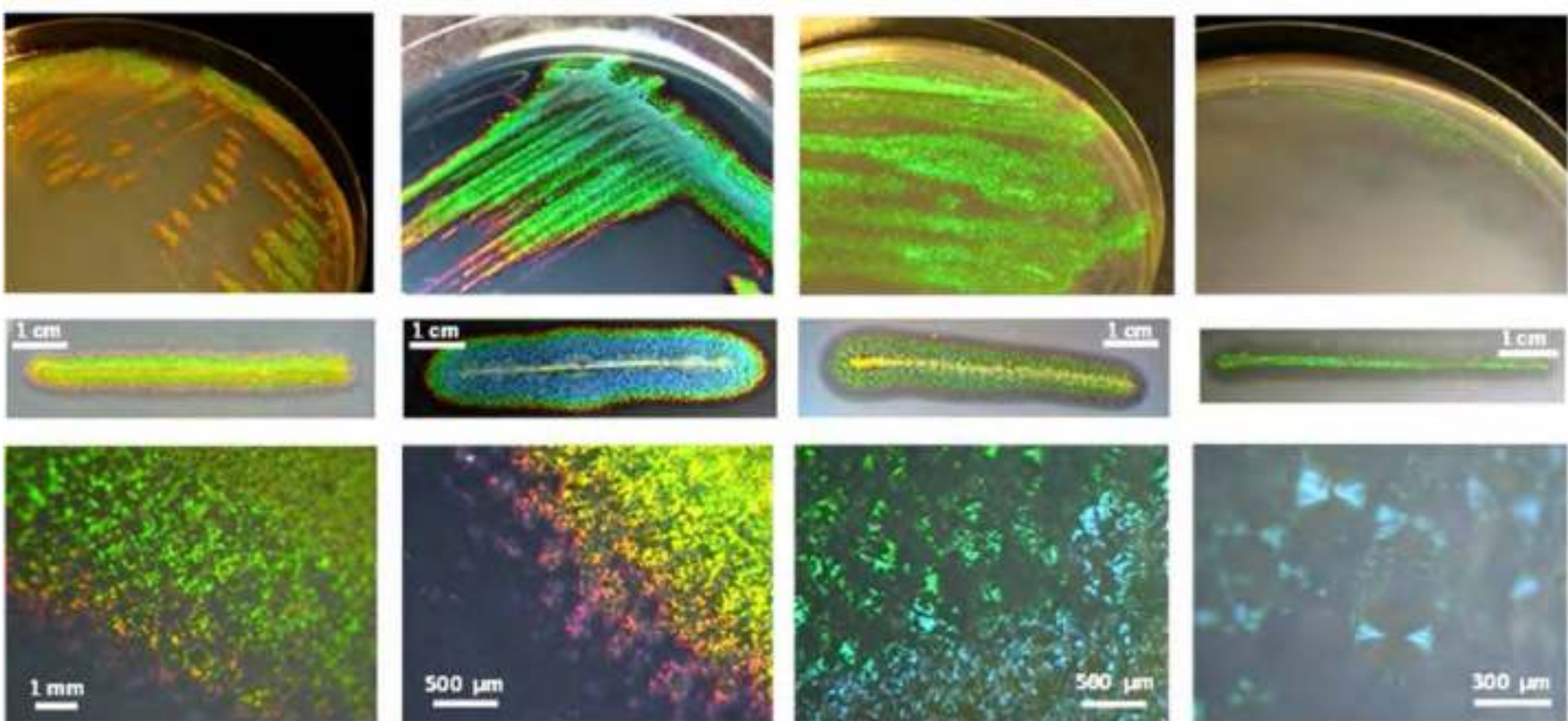


100 frames after 9 secs

30 $\mu$ m 1375V/mm 60fps

«Living crystals «or active «entangled matter»

Experiments at NTNU Trondheim: Tommy Kristiansen



# SCIENTIFIC REPORTS

OPEN

## A unique self-organization of bacterial sub-communities creates iridescence in *Cellulophaga lytica* colony biofilms

Betty Kientz<sup>1\*</sup>, Stephen Luke<sup>2</sup>, Peter Vukusic<sup>2\*</sup>, Renaud Péteri<sup>3\*</sup>, Cyrille Beaudry<sup>4</sup>, Tristan Renault<sup>4</sup>, David Simon<sup>5</sup>, Tām Mignot<sup>5</sup> & Eric Rosenfeld<sup>2\*</sup>

Received: 30 July 2015

Accepted: 17 December 2015

Published: 28 January 2016

DOI: 10.1038/srep11111

www.nature.com/scientificreports/

## Electrohydrodynamic interaction of spherical particles under Quincke rotation

Debasish Das and David Saintillan\*

*Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA*

(Received 3 March 2013; published 29 April 2013)

# Life at low Reynolds number *American Journal of Physics, Vol. 45, No. 1, January 1977*

E. M. Purcell

*Lymna Laboratory, Harvard University, Cambridge, Massachusetts 02138*

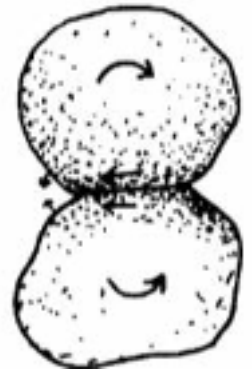
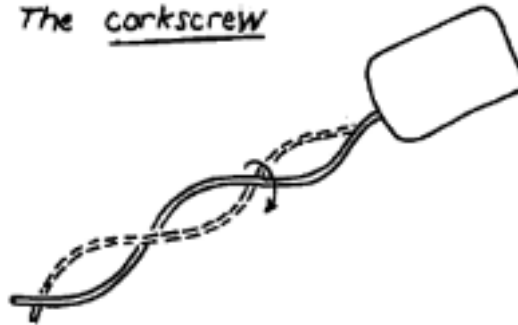
(Received 12 June 1976)

Another animal might consist of two cells which were stuck together and were able to roll on one another by having some kind of attraction here while releasing there. That thing will "roll" along.

*The flexible oar*



*The corkscrew*



Counter-rotating rotors

# Swimmers



Chlamydomonas is a single-cell green alga about 10 micrometres in diameter that swims with two flagella.

Two-rotor bifilament swimmer: Chlamydomonas

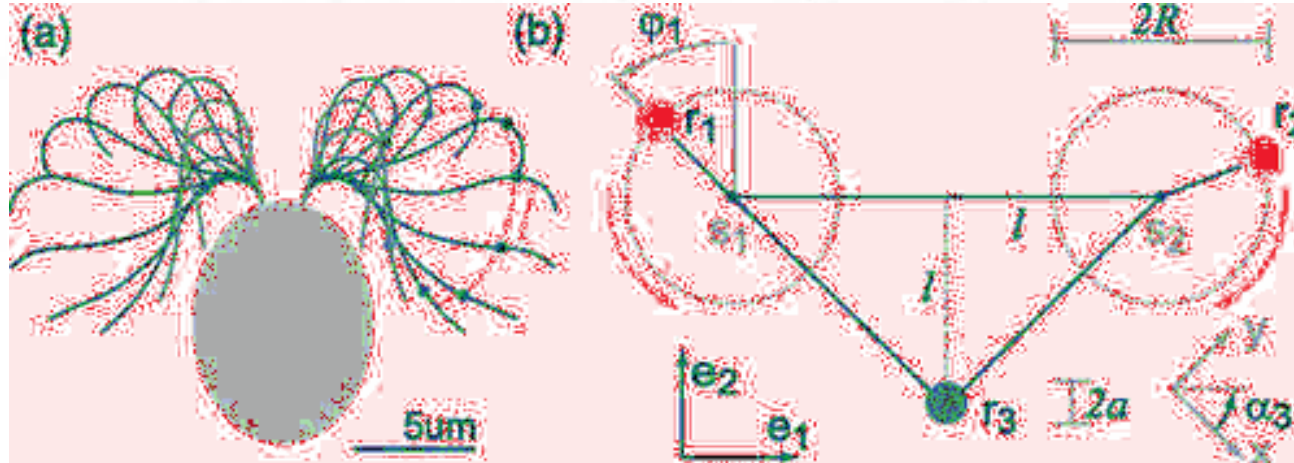


## Flagellar Synchronization Independent of Hydrodynamic Interactions

Benjamin M. Friedrich<sup>\*</sup> and Frank Jülicher

Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

(Received 7 June 2012; published 24 September 2012)



## New Journal of Physics

The open access journal for physics

### Phase-dependent forcing and synchronization in the three-sphere model of *Chlamydomonas*

Rachel R Bennett and Ramin Golestanian<sup>1</sup>

Rudolf Peierls Center for Theoretical Physics, University of Oxford,  
Oxford OX1 3NP, UK

E-mail: [ramin.golestanian@physics.ox.ac.uk](mailto:ramin.golestanian@physics.ox.ac.uk)

*New Journal of Physics* **15** (2013) 075028 (17pp)

Received 10 April 2013

Published 30 July 2013

Online at <http://www.njp.org/>

doi:10.1088/1367-2630/15/7/075028

Two-rotor model of  
bifilament swimmer

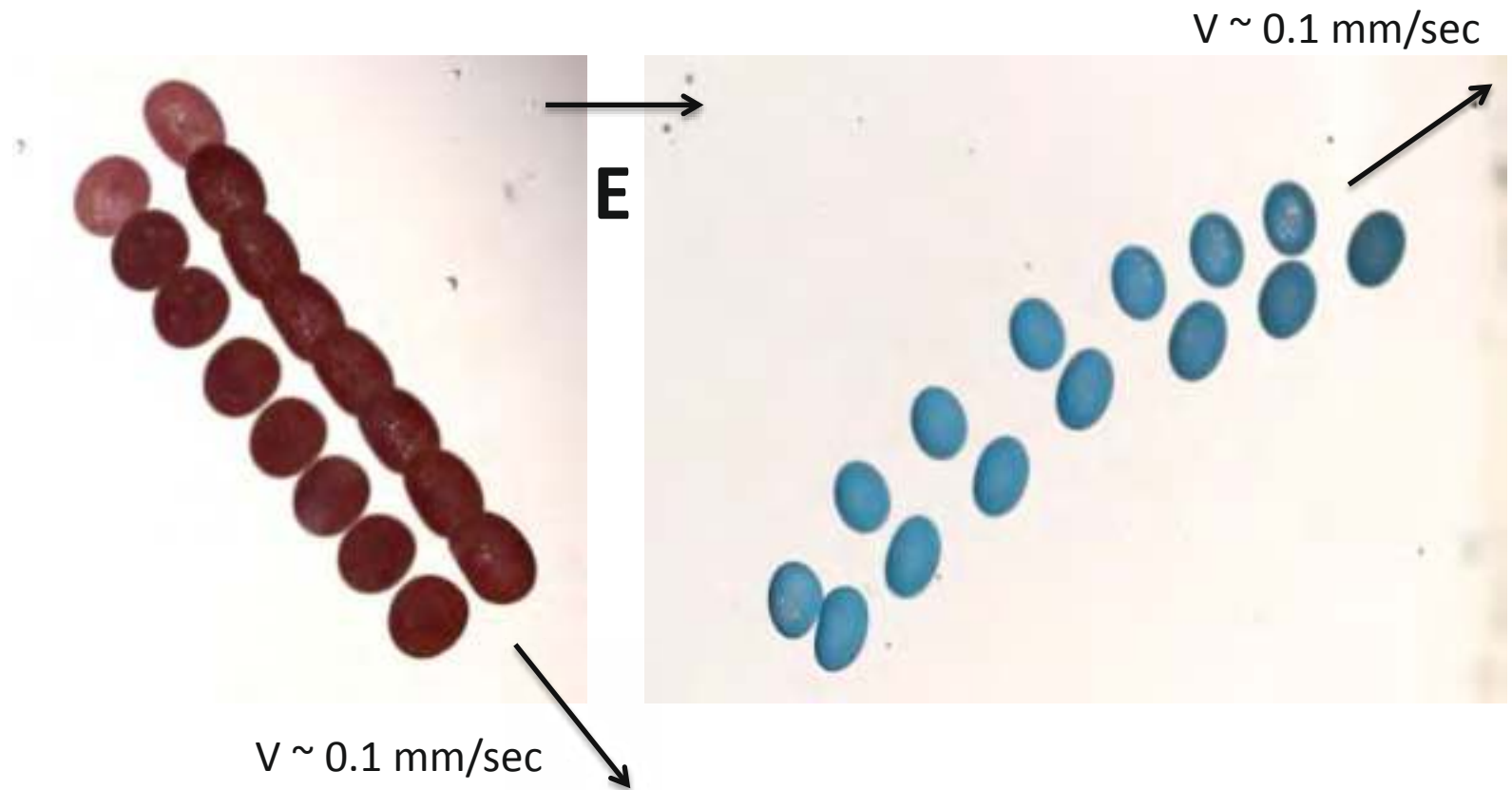
# Swimming upwards

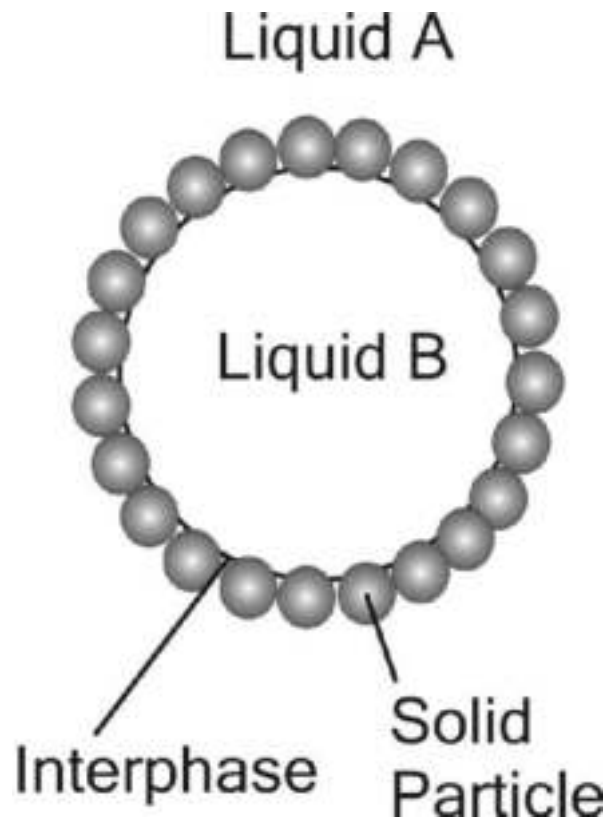


E



## Pair swimming of tank treading capsules





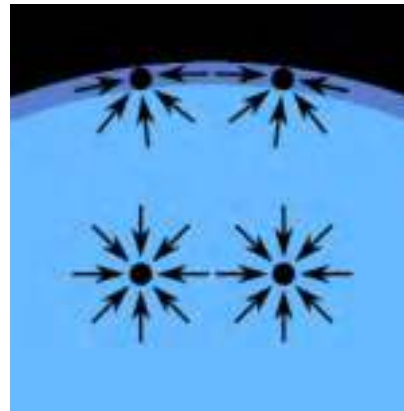
Surface Energy:  $E = \gamma A$

$A$  = Surface area     $\gamma_{WA} = 0.0073 \text{ N/m}$

**Capillary binding:** A particle at the interface is trapped in a capillary barrier with a substantial energy cost of moving to either side of the liquid interface.

Origin of capillary binding:  
**Surface tension:**

The forces on molecules of a liquid:

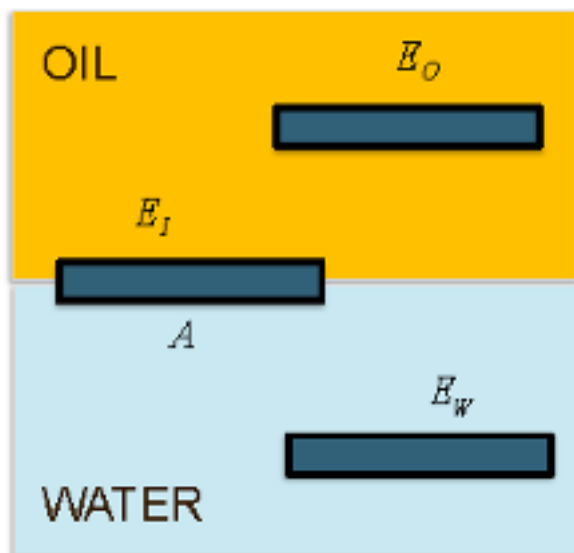


Surface tension preventing a paper clip from submerging



# Capillary binding

## Capillary binding of a flat solid particle at a liquid interface



Particle surface energy :

$$E_O = 2A\gamma_{SO}$$

$$E_W = 2A\gamma_{SW}$$

$$E_I = A\gamma_{SO} + A\gamma_{SW} - A\gamma_{OW}$$

Energy gain :

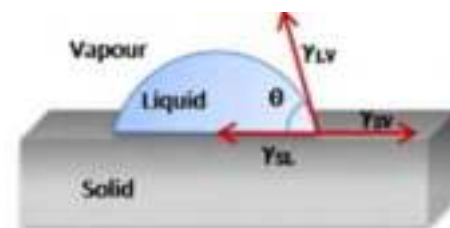
$$E_I - E_O = -A\gamma_{OW}(1 + \cos \theta)$$

$$E_I - E_W = -A\gamma_{OW}(1 - \cos \theta)$$

Wetting angle Young's relation:

$$\gamma_{SO} = \gamma_{SW} + \gamma_{OW} \cos \theta$$

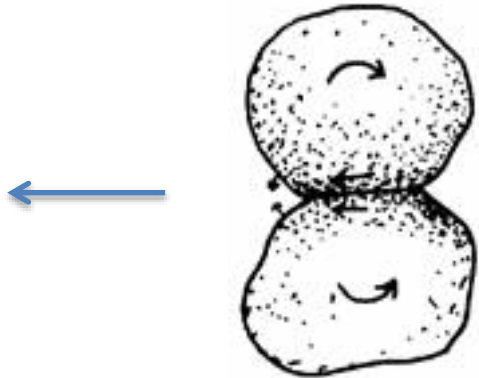
Energetically favorable to adsorb particles at the interface.



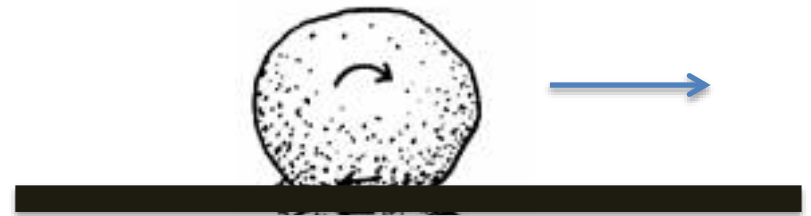
**Typically:**

**$A_p\gamma_{OW} \sim 10000 \text{ kT}$  for microparticles**

## Pair rollers

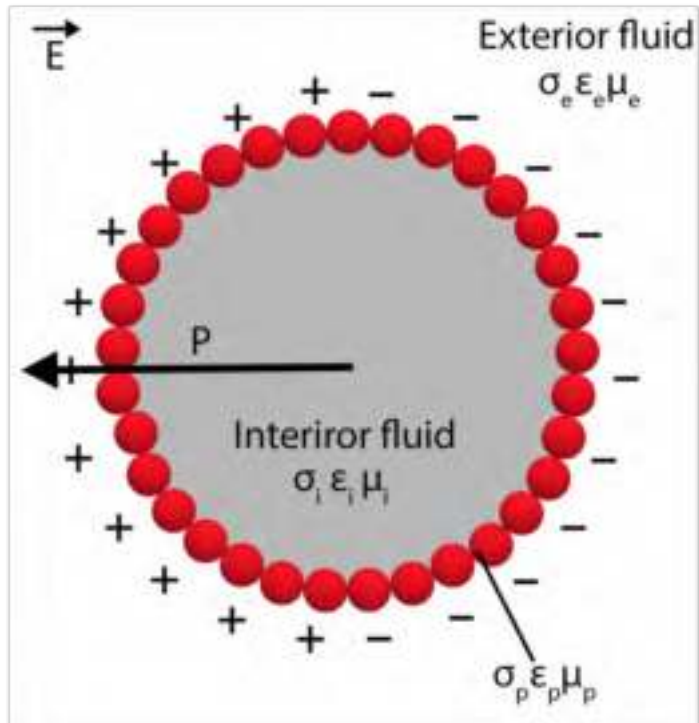


## Surface roller

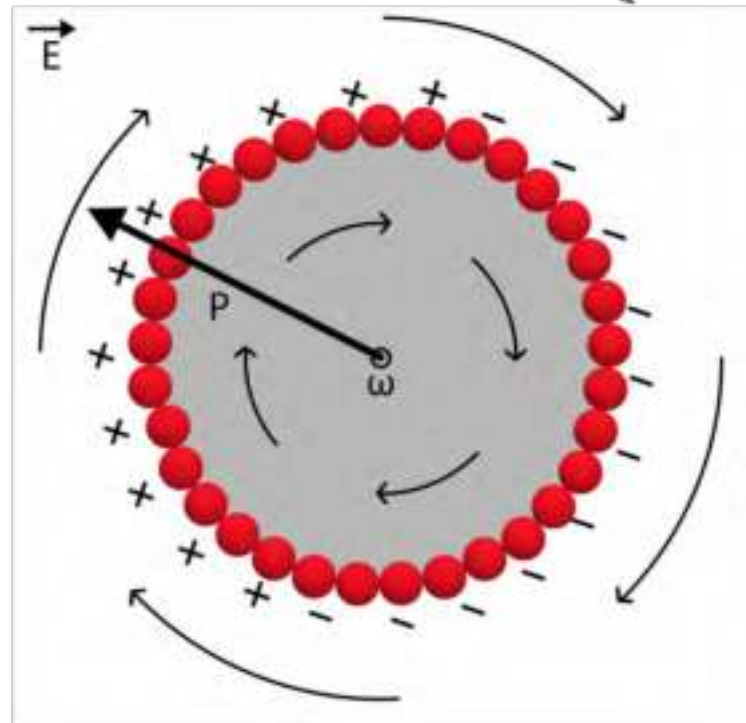


Kicking off one another, or rolling on a surface

(a) Equilibrium ( $E < E_Q$ )



(b) Quincke rotation ( $E \geq E_Q$ )



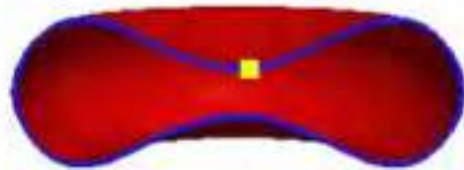
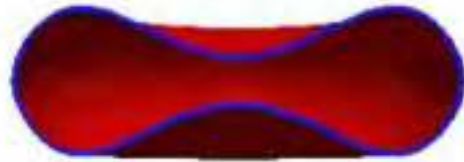


# Movie of single Quincke rotating Pickering drop



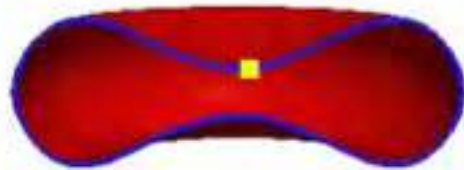
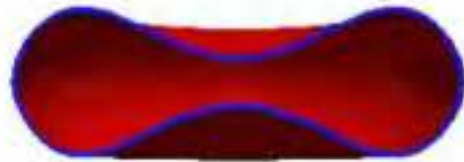
Quincke rotation of Pickering drops. Experiments at NTNU Trondheim

# Tank treading and tumbling motion

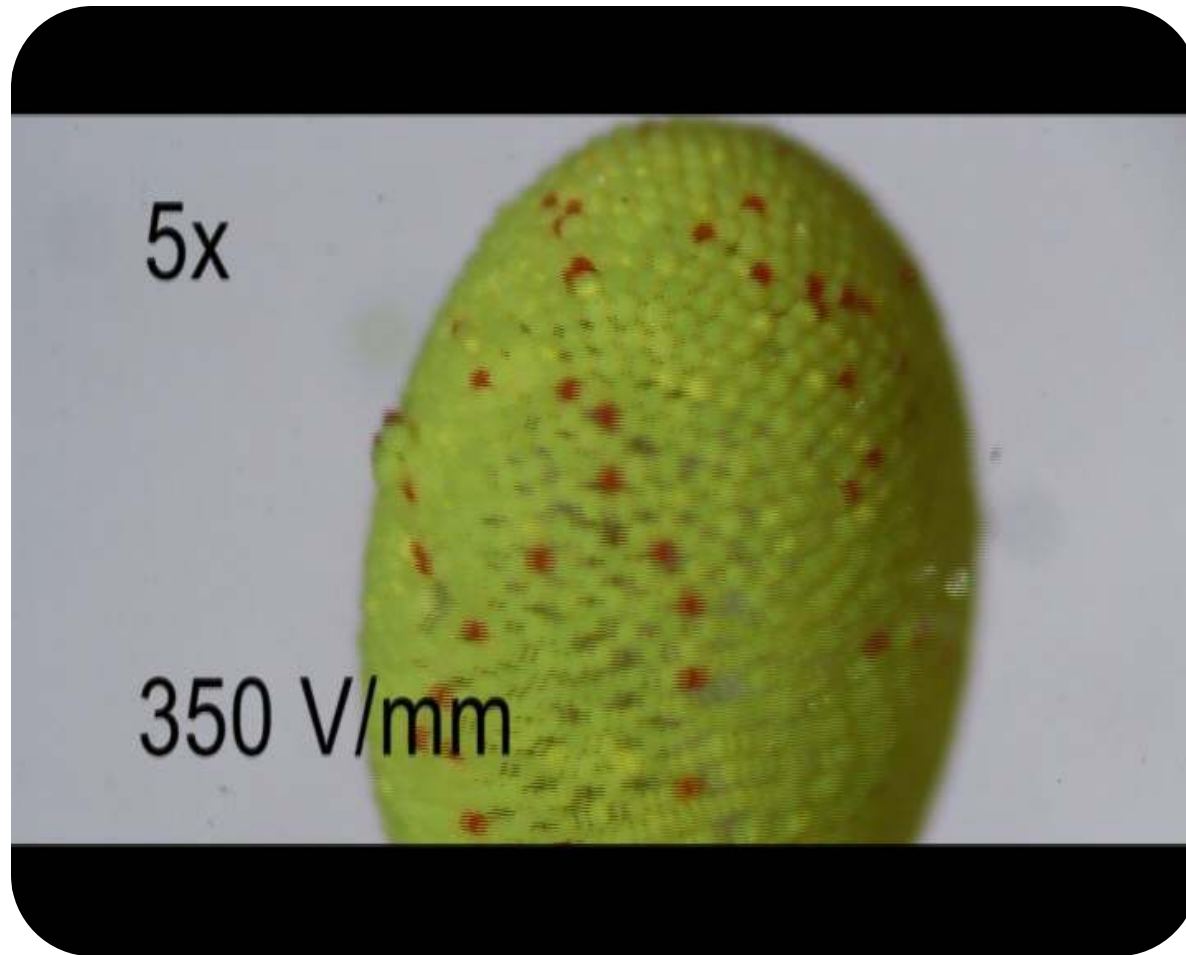


Video from: <http://www.youtube.com/watch?v=mKLhfb5csr4>

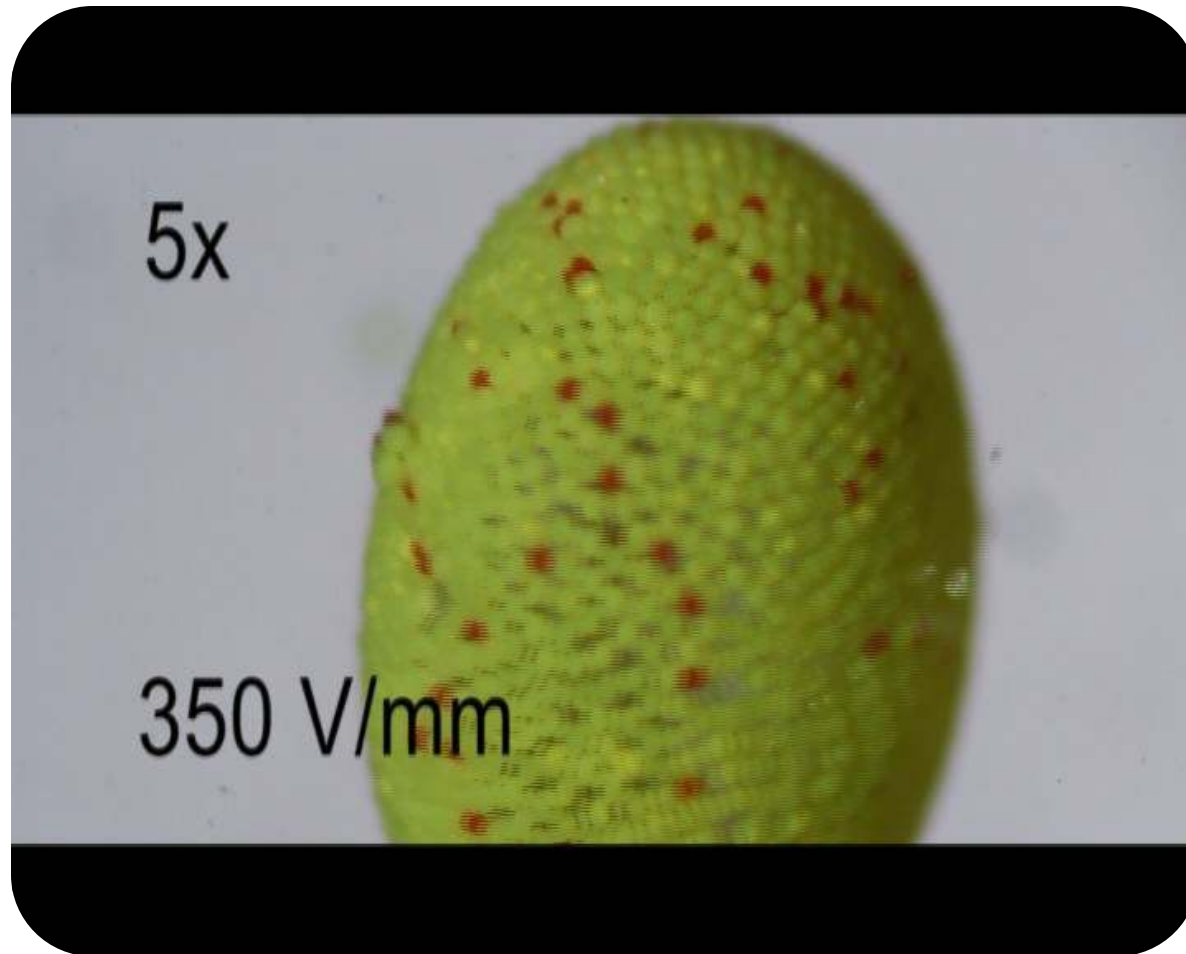
# Tumbling and tank treading motion



Video from: <http://www.youtube.com/watch?v=mKLhfb5csr4>

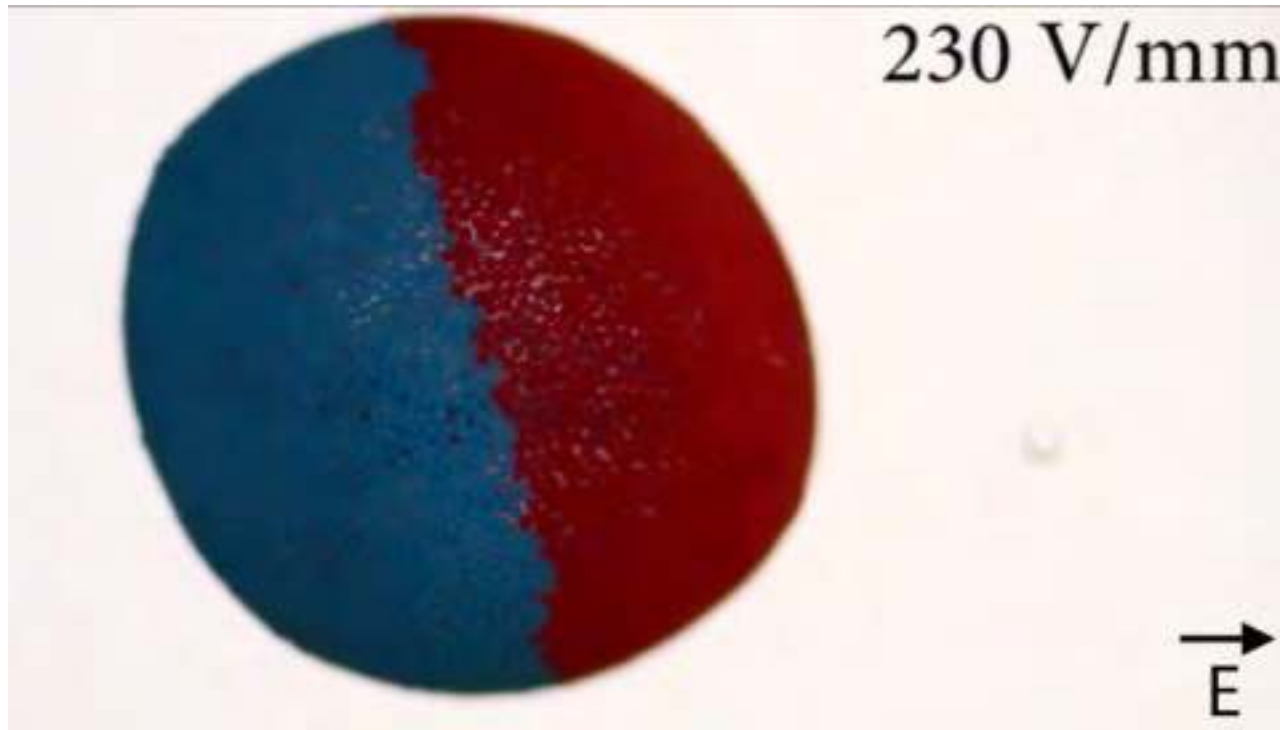


Transition from solid shell rotation to **tank treading**:  
Experiments at **NTNU Trondheim**



Transition from solid shell rotation to **tank treading**:  
Experiments at **NTNU Trondheim**

**Solid to liquid transition of the particle layer occurs when we increase the E-field**





Soft (rheology),  
sticky (adhesion),  
slippery (friction)



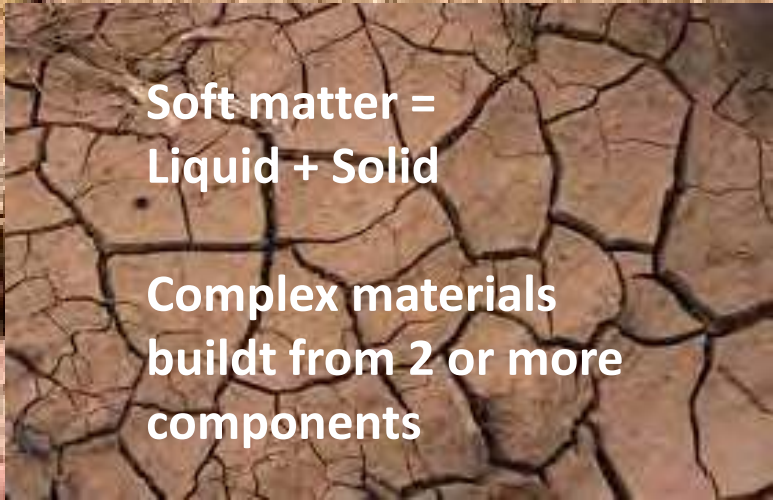
Health and  
well-being

# MUD

is Soft Matter



Soft in processing,  
can be hard in use



Soft matter =  
Liquid + Solid

Complex materials  
built from 2 or more  
components

# Clays in ART

The oldest surviving piece of art:

The oldest sample known of baked clay:

Figurine: "Venus of Vestonice"

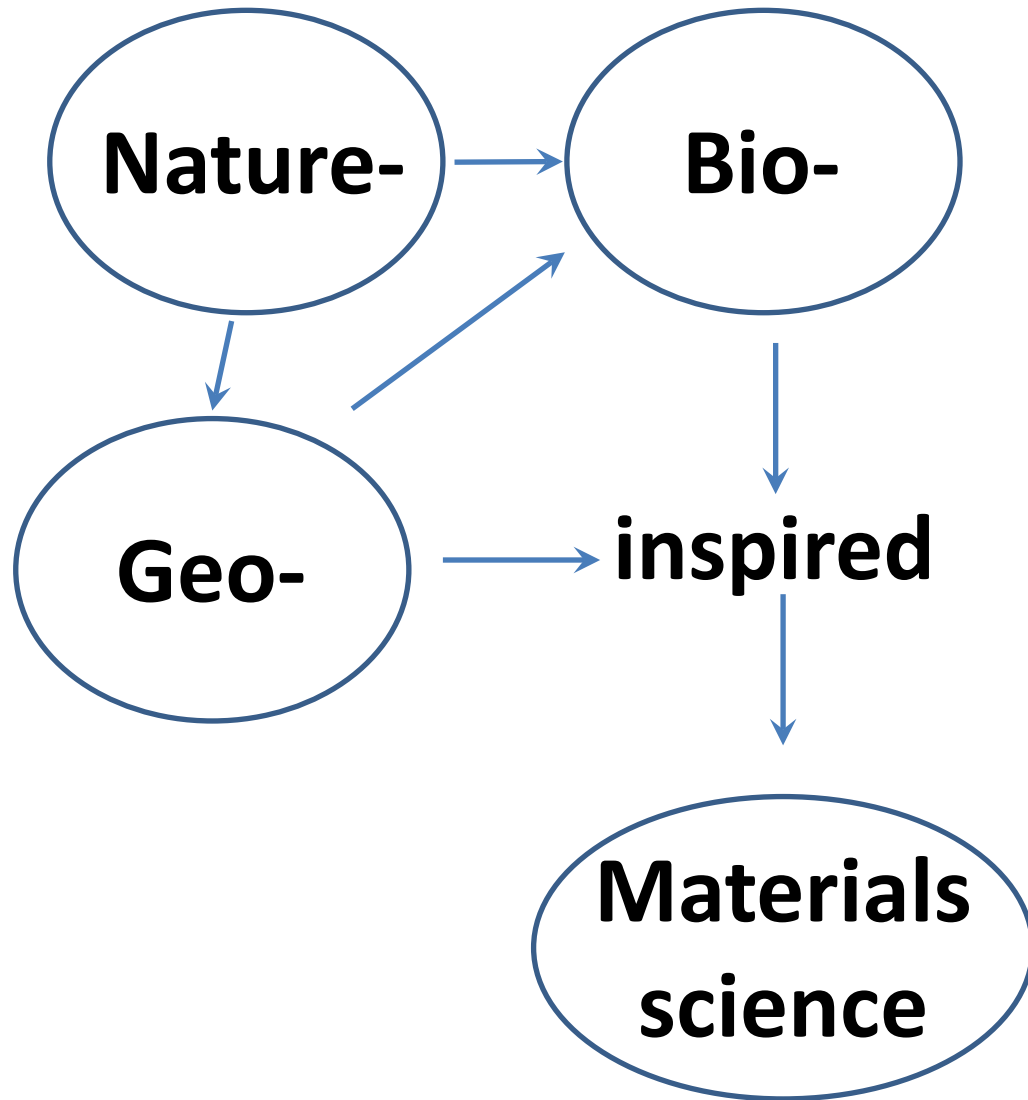
Found in 1920 in the Czech Republic.

**Approximate age: 23000 B.C.**

(Dated from mammoth bone ash in the clay)









# 2017 MRS<sup>®</sup> FALL MEETING & EXHIBIT

November 26–December 1, 2017 | Boston, Massachusetts



Biomaterials and Soft Materials [Expand](#) ▾

Broader Impact [Expand](#) ▾

Electronics, Magnetics and Photonics [Expand](#) ▾

Energy and Sustainability [Expand](#) ▾

Nanomaterials [Expand](#) ▾

Processing and Manufacturing [Expand](#) ▾

Theory, Characterization and Modeling [Expand](#) ▾

- BM01—Multiscale Mechanobiology and Biomechanics—Theory, Experiments, Computations
- BM02—Multiphase Fluids for Materials Science—Droplets, Bubbles and Emulsions
- BM03—Biological and Bioinspired Materials for Photonics and Electronics—From Living Organisms to Devices
- BM04—Biomaterials for Regenerative Engineering
- BM05—Polymer Gels in Materials Science—3D/4D Printing, Fundamentals and Applications
- BM06—2D Nanomaterials in Health Care
- BM07—Emerging Materials and Devices for Engineering Biological Function and Dynamics
- BM08—Materials Design for Neural Interfaces
- BM09—Stretchable Bioelectronics—From Sensor Skins to Implants and Soft Robots
- BM10—Bioinspired Interfacial Materials with Superwettability
- BM11—Modeling, Characterization, Fabrication and Applications of Advanced Biopolymers—Where Form Meets Function
- BM12—Biomolecular Self-Assembly for Materials Design

**Our main motivation for studying clays is that clays may be viewed as good representative model systems for soft condensed matter and complex materials, with "near" applications.**

**Question to ask:**

**How does nano-scale physics (fex. clay nanostructures) translate into macroscopic (fex. clay flow) behaviors?**

<http://www.folk.ntnu.no/fossumj>

<http://www.ntnu.edu/physics/complexmaterials/softcomplex>

# Some of our interconnected clay activities:

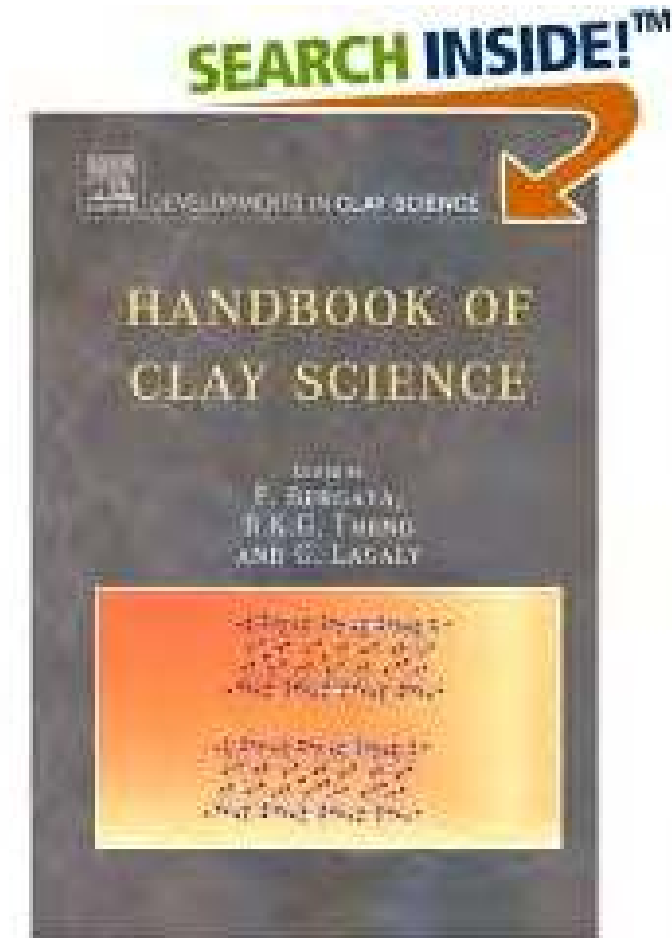
<http://www.ntnu.edu/physics/complexmaterials/softcomplex>

**Macroscopic properties of (clay) gels:**  
Elasticity, flow, fracture processes.

**Molecular transport and capture in clays and related porous media: Capture /release of molecules. Diffusive processes.**

**Self-organization from nanoparticles:**  
Spontaneous and guided self-organization.  
Smart materials. Composite materials.

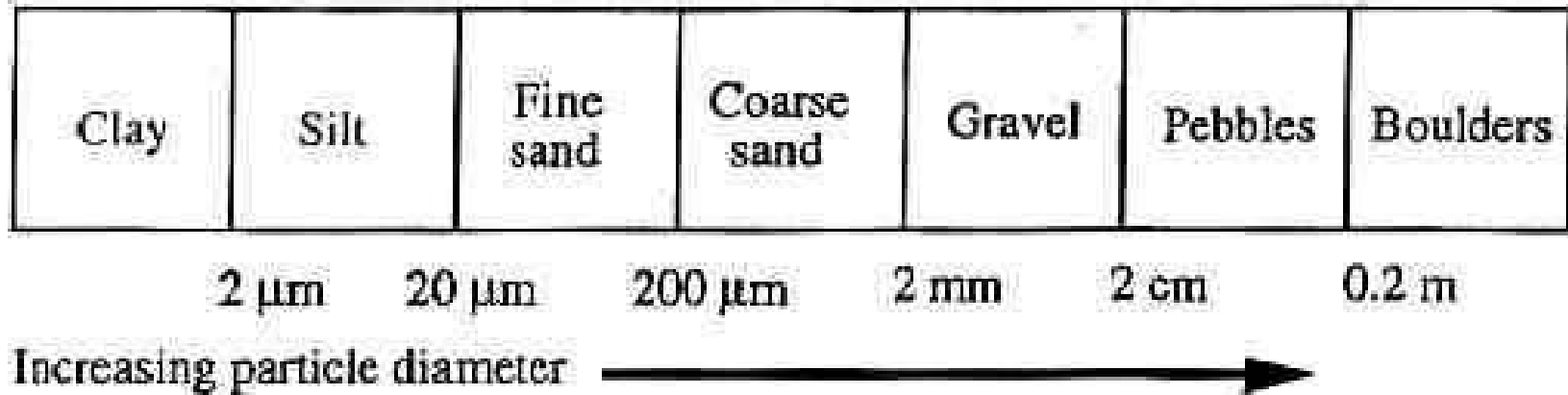
**Clays have a remarkable multitude of practical uses and relevances:**



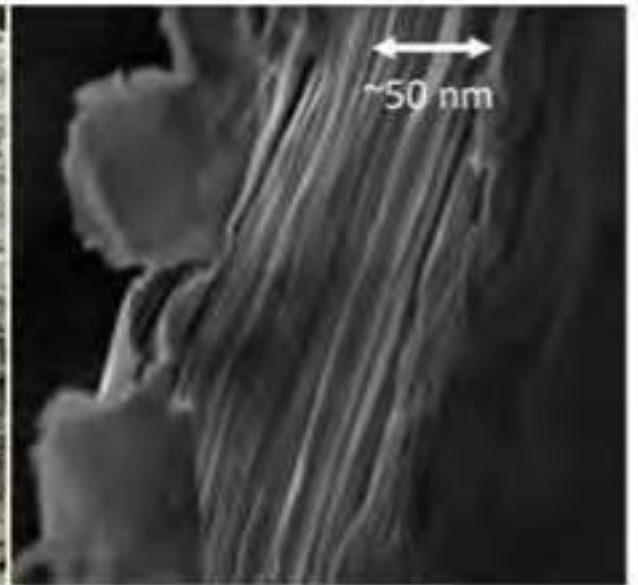
F. Bergaya, B. K. G. Theng, and G. Lagaly,  
editors. Handbook of Clay Science.  
Elsevier, 2006

**As clays and clay materials are abundant, inexpensive and environmentally friendly, they will most likely be known as the materials of the 21st century.**

**Clays are the smallest mineral particles around:**



Grain size classification. [This system is the one used by the International Society of Soil Science.]

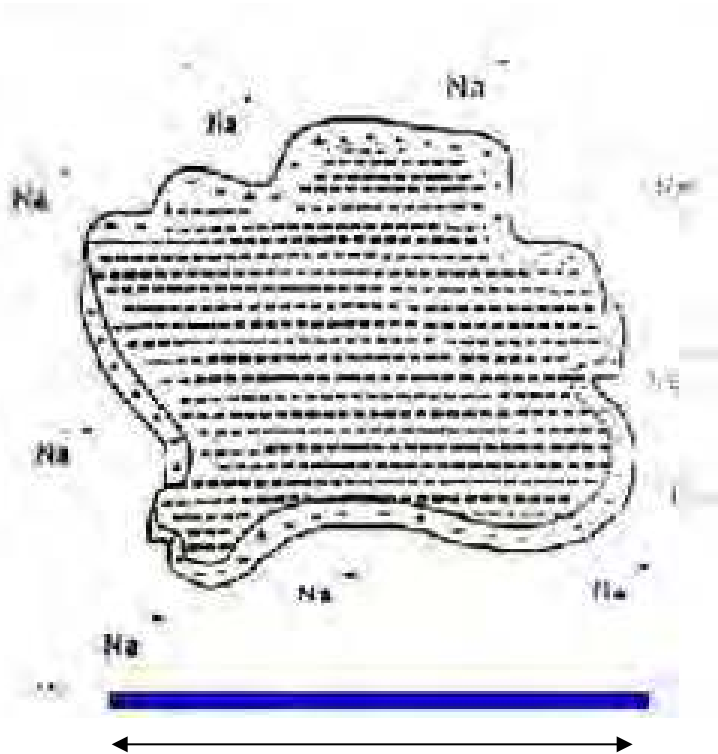


**Figure 1** The left panel above is from a natural clay deposit, and it illustrates on a macroscopic scale that clays are anisotropic materials. The right panel is an electron microscope image of vermiculite clay demonstrating its lamellar structure on the nano-scale, reminiscent of graphene, which is one of the main characteristics of clay minerals.

# Clays are nano-/micro-particles:

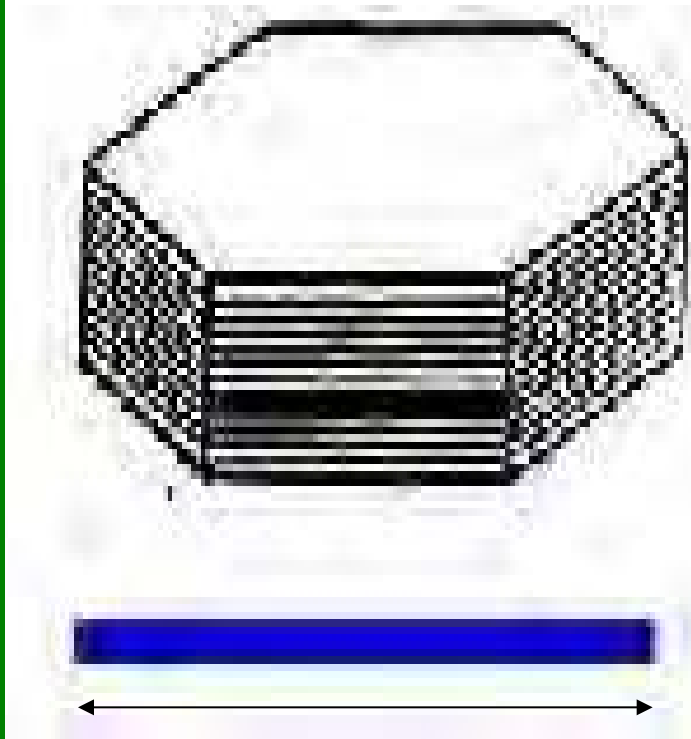
Two basic forms at nano-/micro-scale:

1 nm thick "nanocards"



~ μm

100 nm thick nanolayered particles  
"decks of nanocards"

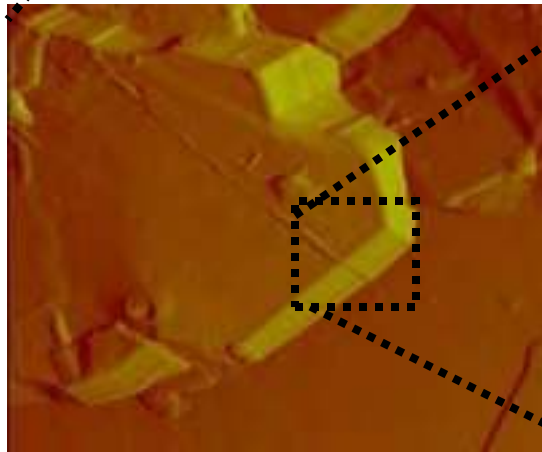
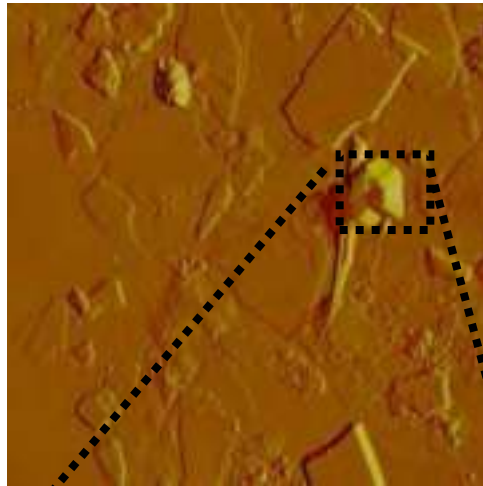


~ μm

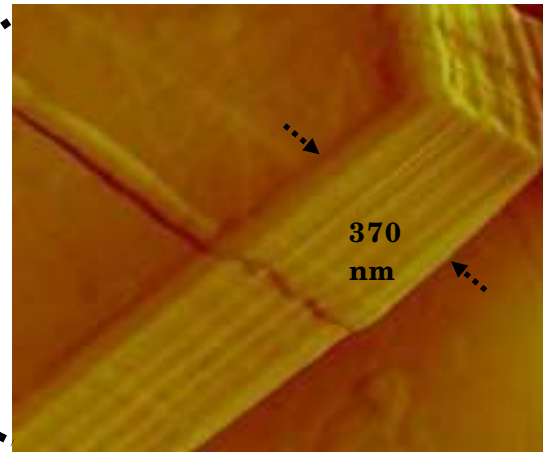


## AFM images of clay stack:

Scan size  
 $25\mu\text{m} \times 25\mu\text{m}$



$5\mu\text{m} \times 5\mu\text{m}$



$1.2\mu\text{m} \times 1.2\mu\text{m}$

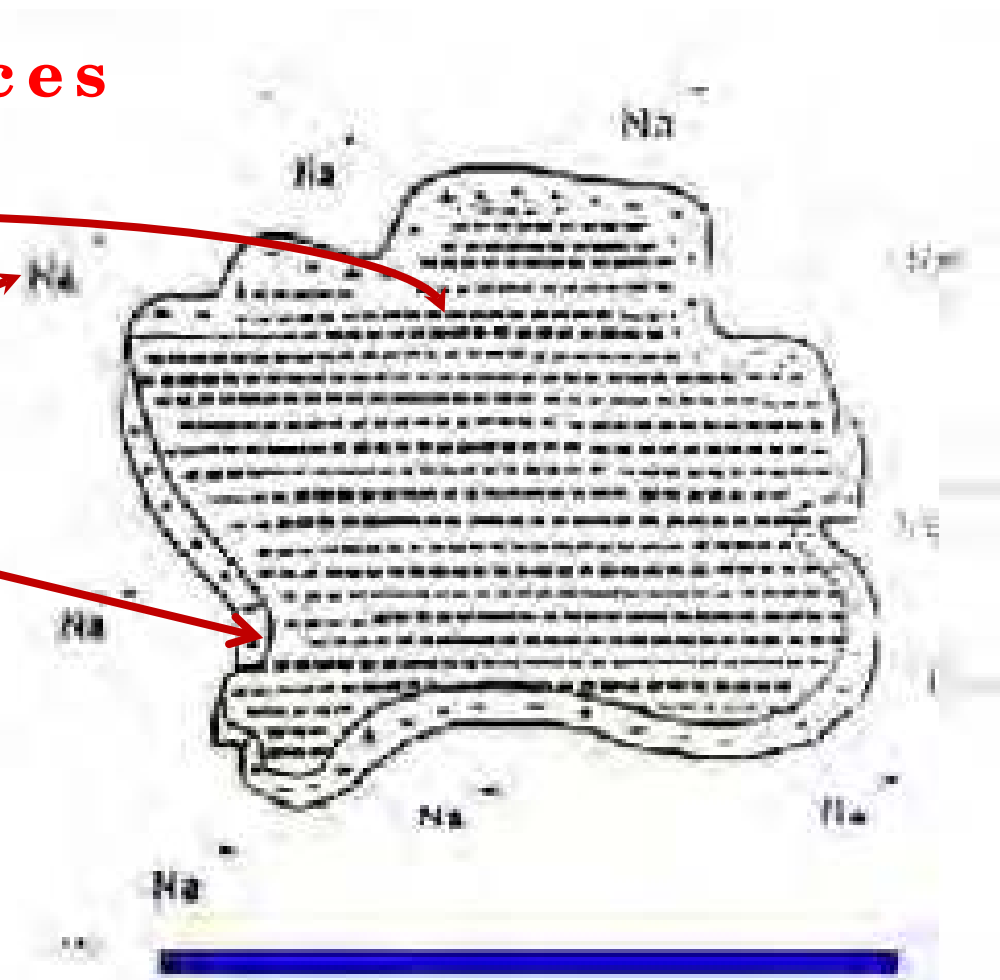
# Important for structures and behaviors:

## Clay particle platelet shape

## Charged clay surfaces

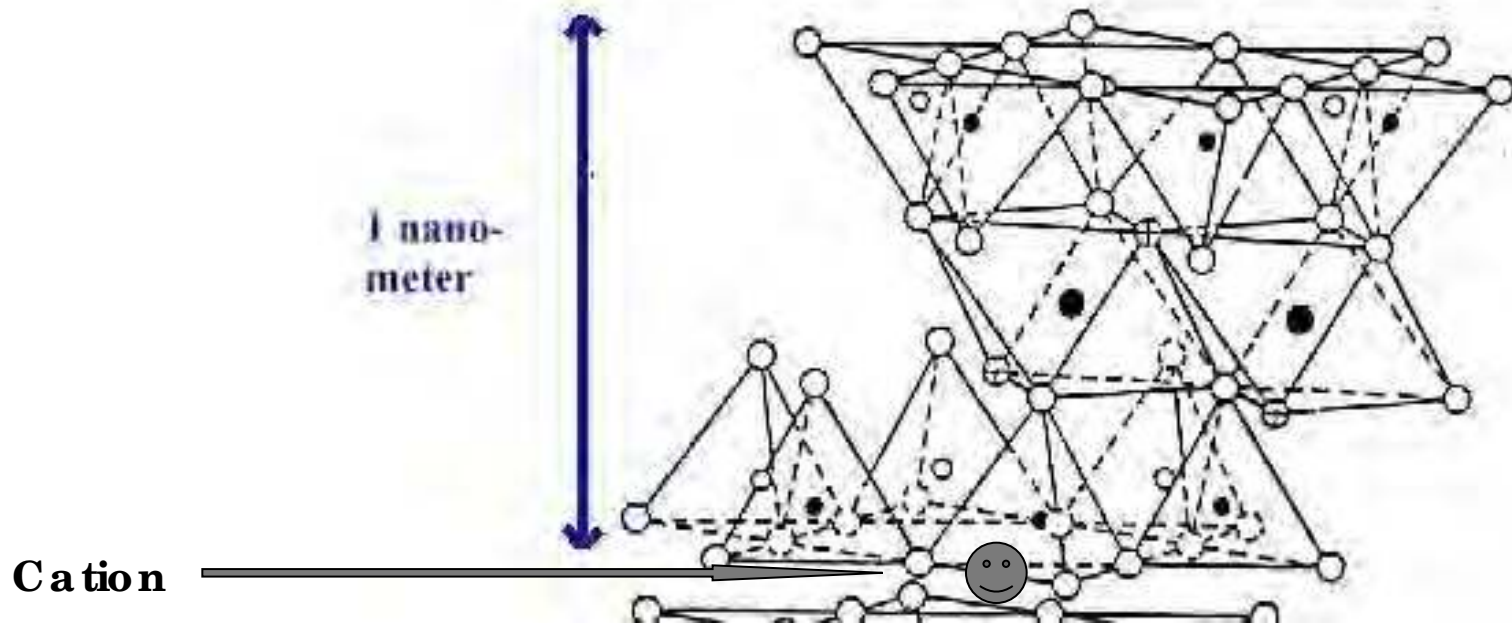
Negative surface charge compensated by cations

Small positive edge charge

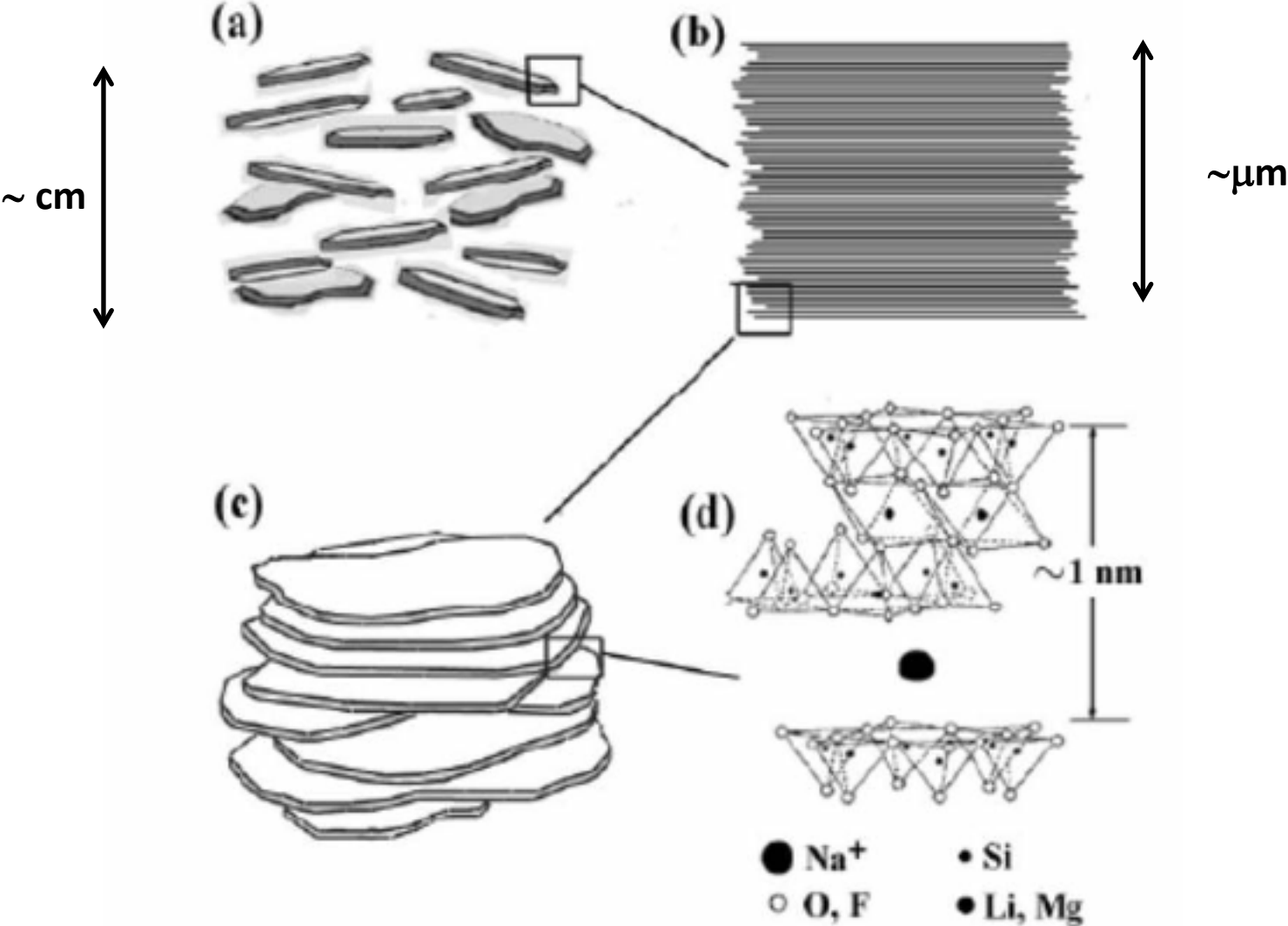




Each individual swelling (smectite) clay card is a mesoscopic single crystal with a well defined crystal structure, consisting of three atomic layers, two identical outer layers (Si + O), and a single middle layer (metals + OH), thus the name 2:1 clays:



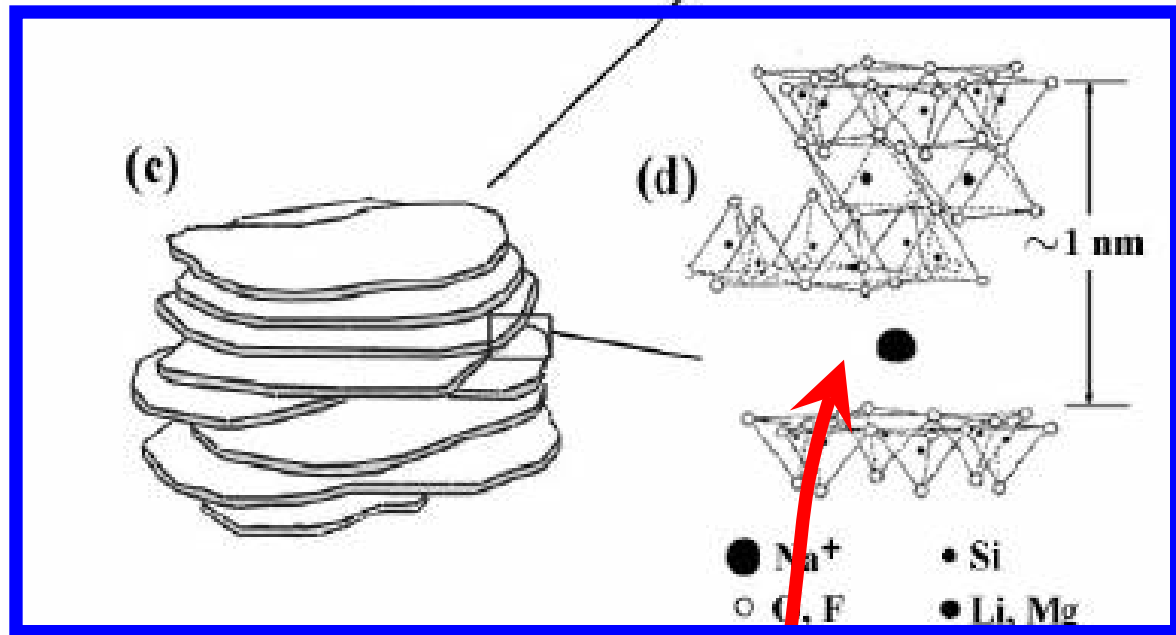
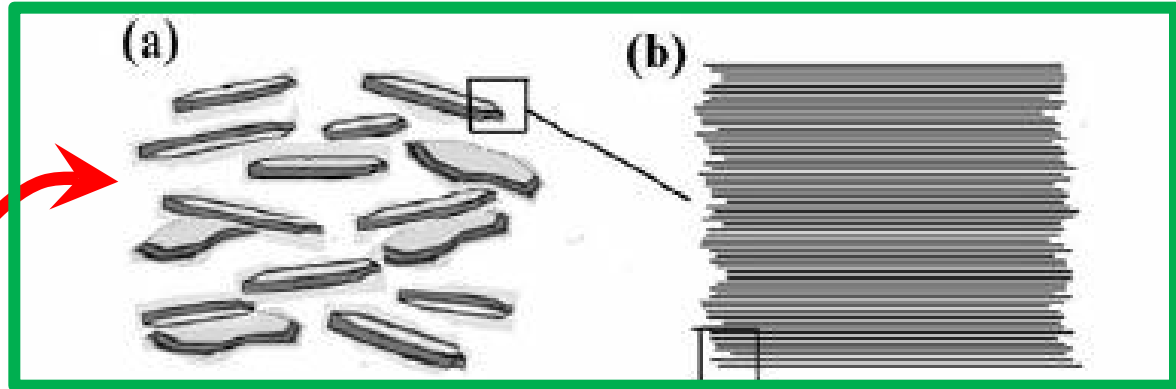
# The nano-/meso- structures behind clayey behaviour



Levels of description:

Nanoparticle aggregates

Nanoparticles

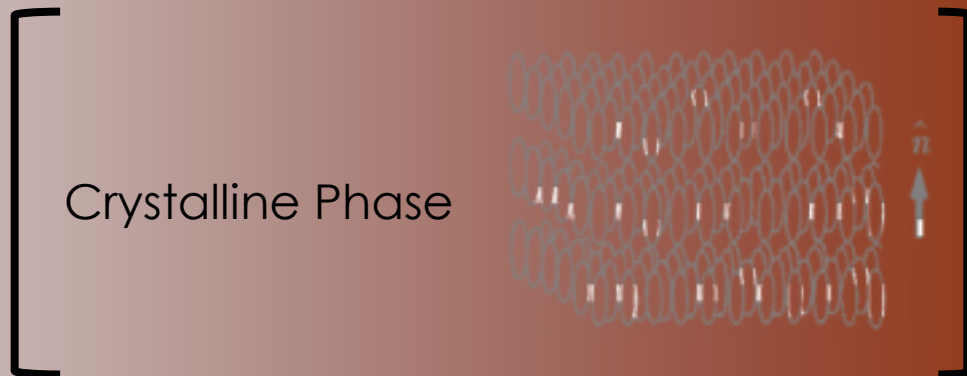
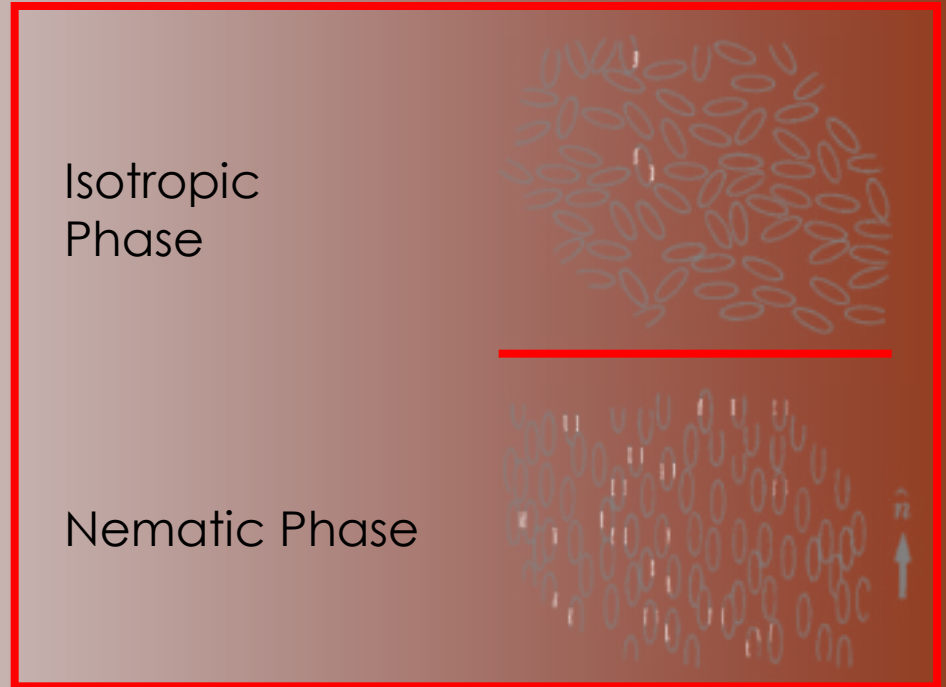
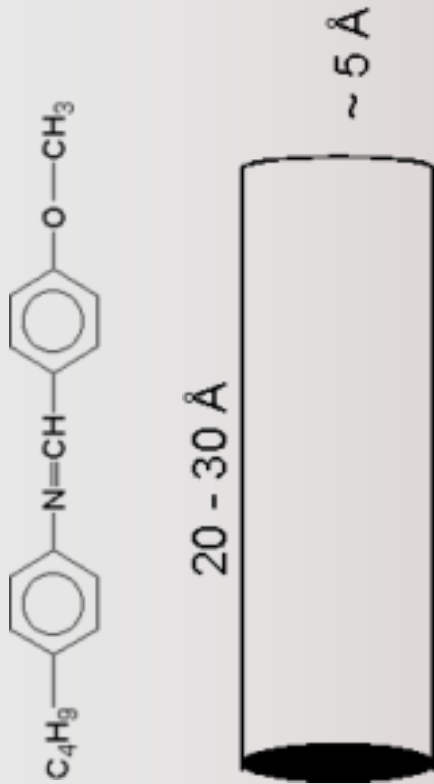


# **SELF-ORGANIZATION OF CLAY PARTICLES**

# LC P = Liquid Crystalline Phases

Chemistry    Physics

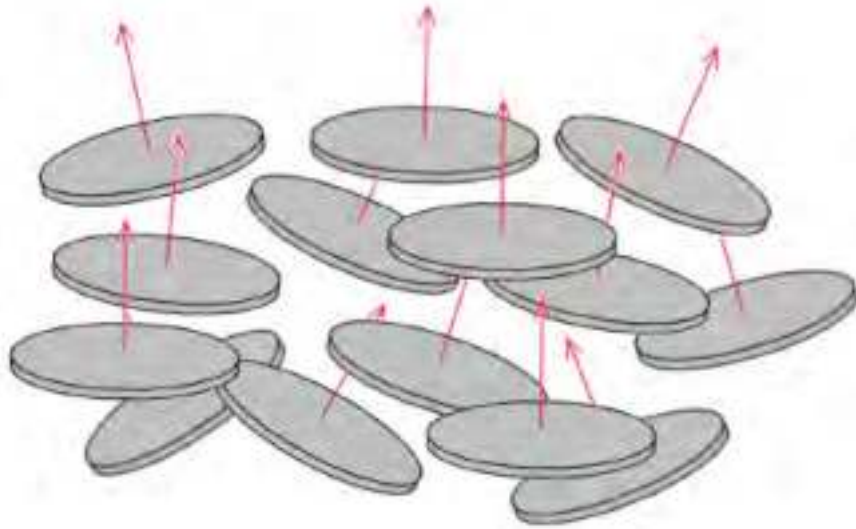
from particles with shape, fex. rods:



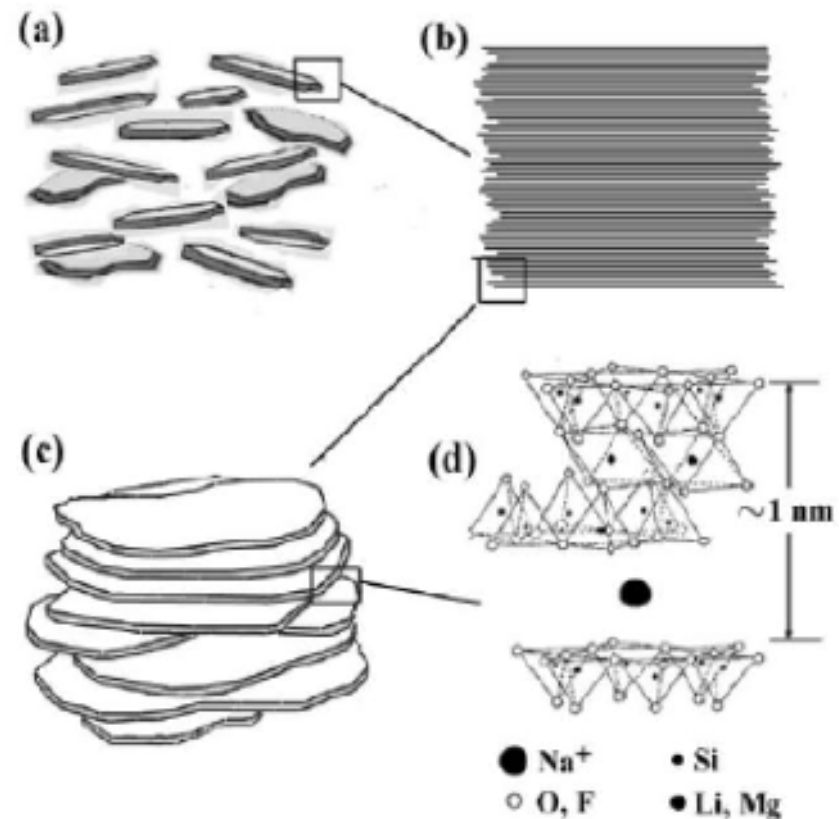
LCD  
technology

# LCP = Self-Organized Liquid Crystalline Phases

Nematic order of discs:



Clays are disc-like nano-/micro-particles:





**Alignment of particles with shape (i.e. not spherical) has been of basic scientific interest to physicists and chemists for a long time:**



**Irving Langmuir: Nobel Prize in Chemistry 1932**

**Langmuir did pioneering experimental work in 1938 on finding liquid crystal structures in a clay.**

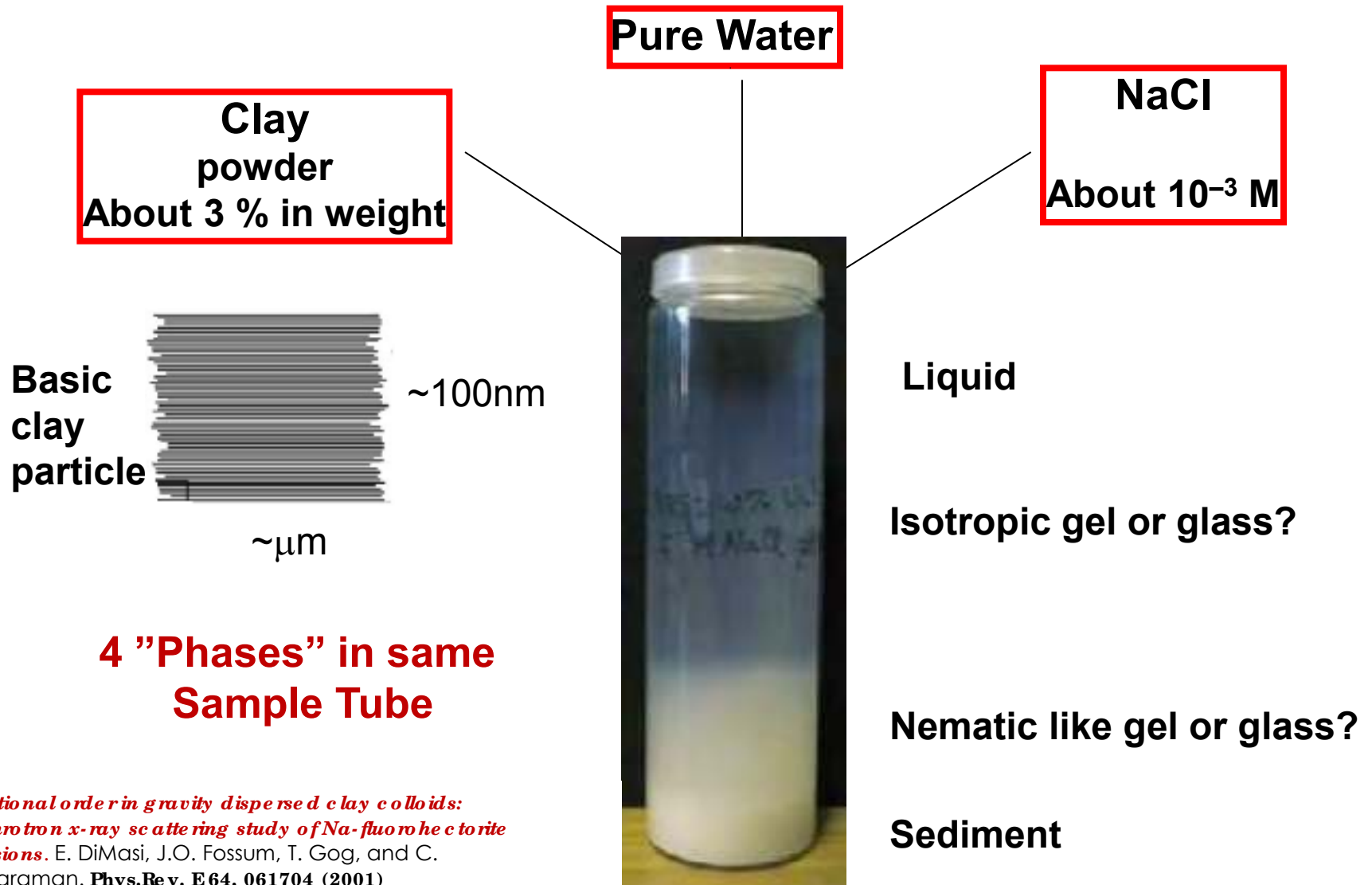
**J. Chem Phys. 6, 873 (1938)**



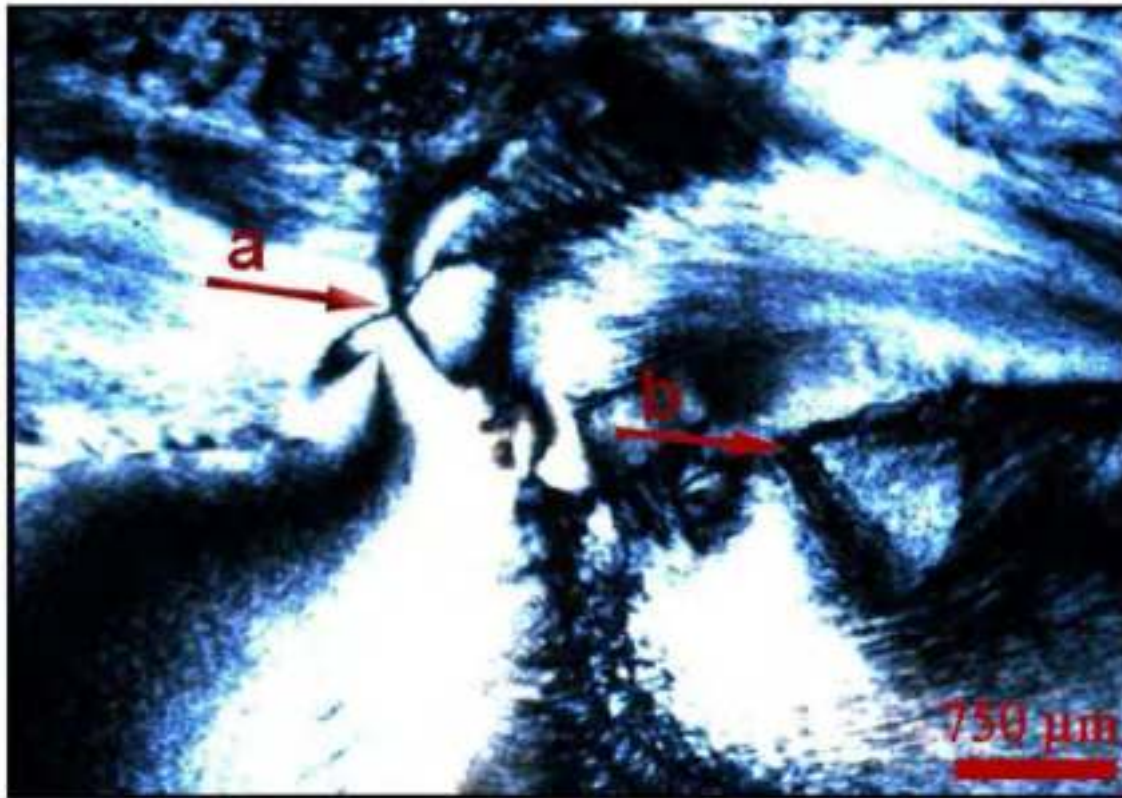
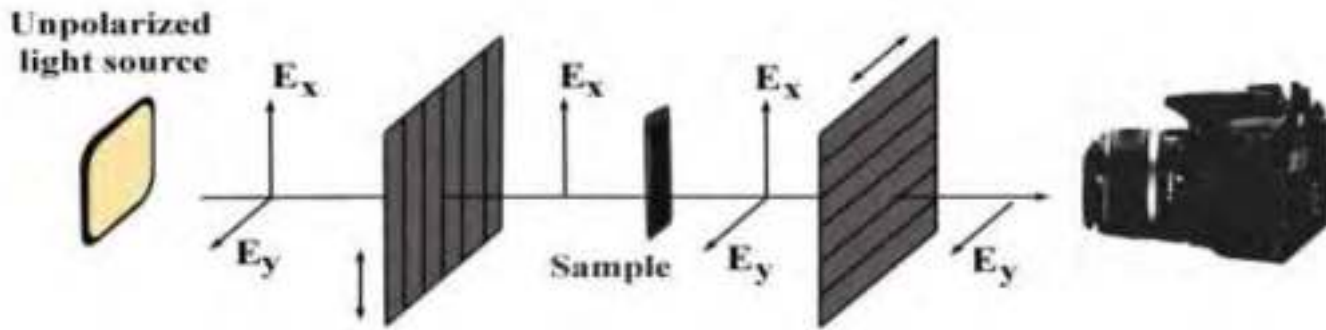
**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

# One of our experiments:

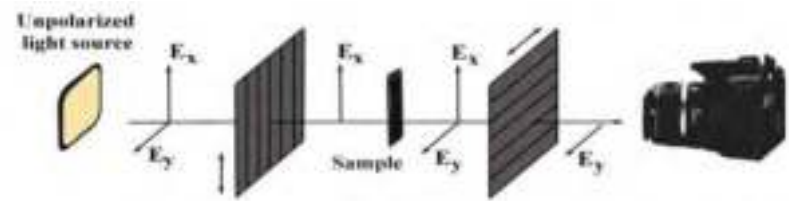
<http://www.ntnu.edu/physics/complexmaterials/softcomplex>



*Orientational order in gravity dispersed clay colloids: A synchrotron x-ray scattering study of Na-fluorohectorite suspensions.* E. DiMasi, J.O. Fossum, T. Gog, and C. Venkataraman. **Phys.Rev. E** 64, 061704 (2001)



**a and b** are "typical" nematic defect signatures: Disclinations ("discontinuity" in the "inclination" of the director)



# Self-organization by sedimentation clay particles in H<sub>2</sub>O:

*complex* @ NTNU - Norwegian University of Science and Technology

<http://www.complexphysics.org/> <http://folk.ntnu.no/fossumj/>



0 days

*Experiments by Nils Ivar Ringdal*