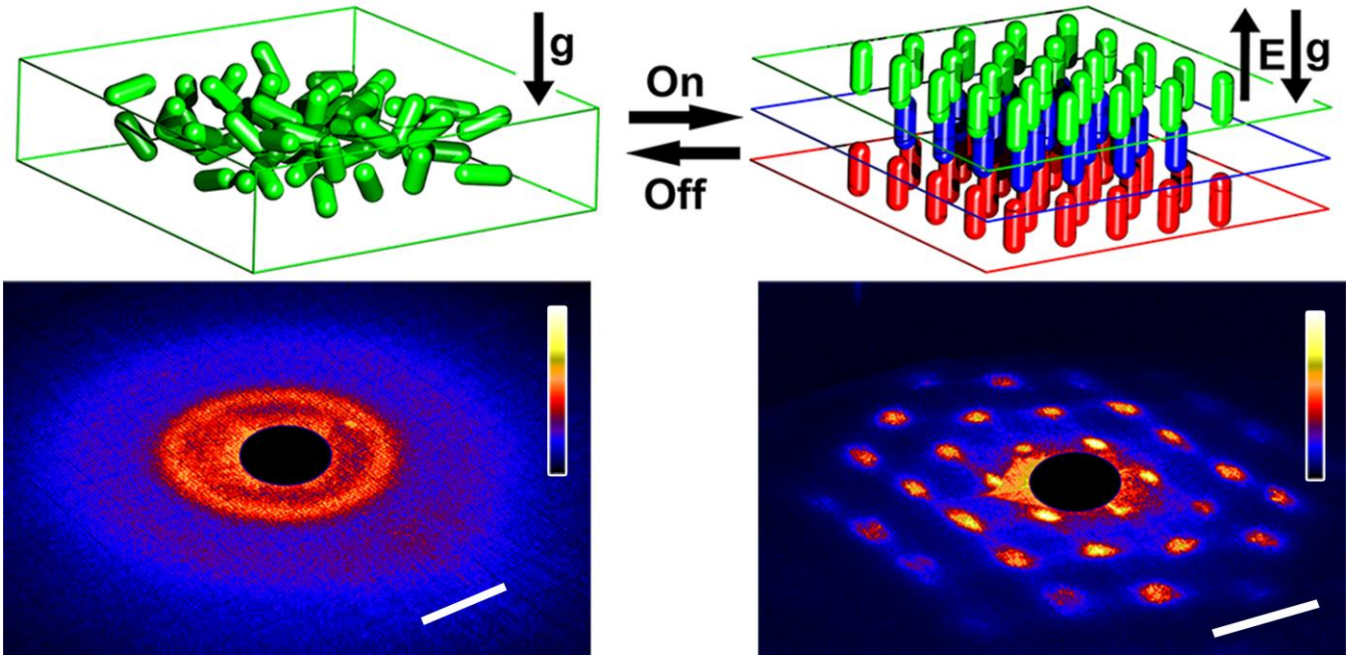
FOM - 14.0191

Annual report 2013

FOM programme nr. 61
'Physics of colloidal dispersions in external fields'

Foundation for Fundamental Research on Matter
www.fom.nl



A two-dimensional confocal microscope image of a three-dimensional plastic crystal. Left a snapshot of the particles can be seen. The right-hand image is averaged over a longer period of time. From this it can be seen that the particles are positions in a 3D lattice while the rods are still free to rotate.

May 2014

Content

1. Scientific results 2013

Historical background: FOM programme 61 is the University of Utrecht, Debye Institute for Nanomaterials Science participation in the first two rounds in the German Transregio Sonder-ForschungsBereich 6 (SFB TR 6: Transregional Collaborative Research Centers) *Physics of Colloidal Dispersions in External Fields*. The Dutch FOM programme is (compared to other FOM programmes relatively small) with two rounds of three researches (two PhD students, one PD). The first round was completely finished in 2008 with the PhD defense of the second PhD student, at this point in time (April 2014) this programme is close to finishing: one of the two PhD students has defended her PhD successfully and the postdoc project has finished as well. Both found positions elsewhere. The last PhD student will defend his Thesis in 2014.

A Transregional Collaborative Research centre is the largest DFG programme for coordinated network-based research; to get and keep one funded is highly prestigious in the German scientific community. A TR SFB enables scientists to form interdisciplinary communities that engage in long-term research, for up to twelve years, on a jointly selected subject. The key objective is to promote excellent research on an ambitious topic by focusing resources at the host universities. When this FOM programme started it was for the first time allowed to add one foreign university site to the scheme of German network sites. In SFB TR 6 the participating sites are: Düsseldorf/Jülich, Konstanz, Mainz, Utrecht. The Executive board of FOM allowed this programme to take part in the third and final round of research that was organised by both the DFG and FOM. The last part of this programme of again projects for three researchers was allocated after an extensive international review round in April 2009.

The formally '*Final SFB TR6*' internal meeting (however, several invited international speakers were also present) was held 5-7 March 2013 in Mainz. Details and the programme are still available at: **www.codef.de** . More info on the complete network is available at: **www.sfb-tr6.de** including a yearly newsletter. A special issue in the *European Physical Journal* devoted to papers published of all projects at the CODEF III conference (including a short literature review in two papers from the FOM groups) has been prepared and appeared some months ago. Despite the fact that in 2015 the German part of this collaboration will have formally ended, money is being sought to continue the international CODEF (Colloids in External Fields) conferences for a 4th version in that year.

The highlight from the FOM year report of this programme was from results of a postdoc project (B. Liu) from the second round. This work on the first realization of colloidal plastic crystals, the counter part of liquid crystals, was published in *Nature Communications* [3]. It was found that plastic crystals, solids for which the particles are ordered on a 3D lattice, but still have rotational freedom on the lattice, are not only interesting for photonic applications, but are also a powerful model system to study the effects of rotations on crystallization and the glass transition. As was already mentioned in the *NC* paper and has been worked out in follow up papers (of which one has already been submitted, see below) it is possible to reversibly switch between a plastic glass and a 3D crystal with an external electric field (see the highlight). In addition we found that by confining either spheres or rods with long-ranged repulsive charge interactions intriguing phase behaviour results. For instance, as a function of distance between two confining plates an alternation of symmetries occurs, just as with spheres, but in addition an alternation between crystalline and plastic crystalline phases is found (work submitted). Several papers are also being prepared on rods made to order in a spherical confinement (see Figure below).

The other project in the combined theme of this last round of projects: phase behaviour of colloidal (liquid crystal) phases in confinement on structure formation in columnar mineral liquid crystals has ended with the PhD defense of Anke Leferink op Reinink (March 2014). Among the interesting

results obtained in 2013 is the discovery of novel approaches to influence the phase behaviour of suspensions of board-shaped colloidal particles. In particular, it is shown that the depletant-induced attraction between the particles can promote the formation of the rare biaxial nematic and smectic phases, in which particles are orientationally ordered in all three dimensions. In addition, it is found that the biaxiallity can also be tuned by an external magnetic field as characterized by synchrotron small angle X-ray scattering.

PhD student Thomas Troppenz continued his project on '*Phase transitions of confined nanorods in electric fields*'. The polarization of single dielectric colloidal rod in an external E-field is not simply parallel to the E-field (with a scalar polarisability as a prefactor) but rather it depends tensorially on the orientation of the rod with respect to that of the E-field. Within the so-called coupled-dipole method, in which the colloidal rod is viewed as a collection of many induced dipoles, we have theoretically calculated the polarisability tensor using linear-algebra manipulations involving large-matrices. On this basis we have made several further studies. We have calculated the orientation distribution function and the nematic order parameter of dilute suspensions of micron-sized colloidal rods in an E-field, and compared this with experimental confocal microscopy observations.

In order to study the bulk phase behaviour of a suspension of rods as a function of concentration and field strength by simulation, we described the polarization of each rod by a simple but rather accurate model of two opposite point charges close to either end. We find a rich phase diagram, involving the expected (string-) fluid phase at low densities, but also liquid crystalline and a variety of crystalline states at higher densities. In order to make the next step towards the proposed plan to study rods in emulsion droplets in E-fields, we have also begun to theoretically study rods near penetrable liquid-liquid interfaces. For planar geometries we find interesting interface-induced orientational ordering and a wetting transition (from complete to partial) upon lowering the penetration penalty.

2. Added value of the programme

The Dutch projects in the first two rounds and FOM's involvement in the German selection and evaluation process were not only evaluated as being highly successful, there was also an important synergy and participation of the Dutch groups that went well beyond the funded PhD students and postdocs. This synergy is apparent from the high impact of the joined papers together with scientists within the network (see the special issue in *EPJ*) and the strong attendance of the schools and meetings that were organized by the network. Some of these were meetings where only non-permanent scientists, PhD students and postdocs, were present. In all cases the participation and travel costs were reimbursed and extended to *all* group members, not only to those funded by the network. (often also other FOM students from the groups). Furthermore, there has been a generous amount of DFG money also available to the Utrecht groups to invite guests for talks, visits or even sabbatical stays. A new call in Germany on active colloids has been approved by the DFG which directly resulted from the Programme and a new FOM programme on active colloids will also be proposed this year.

3. Personnel

Two projects finished (PhD 19 March 2014, one pd); researchers found other positions. One PhD planned for 2014.

4. Publications

09CDEF07

- *A. Kuijk, Th. Troppenz, L. Filion, R. van Roij, M. Dijkstra, A. imhof, A. van Blaaderen*, Effect of external electric fields on the phase behavior of colloidal silica rods, submitted 2014.
- *A. van Blaaderen, M. Dijkstra , R. van Roij, A. Imhof, M. Kamp, B.W. Kwaadgras, T. Vissers, and B. Liu*, Manipulating the self assembly of colloids in electric fields, European Physical Journal Special Topics 222, 2895-2909 (2013).
- *B. Liu, T.H. Besseling, M. Hermes, A.F. Demirörs, A. Imhof, and A. van Blaaderen*, Switching plastic crystals of colloidal rods with electric fields, Nature Communications, 5: 3092, 2014.

09CDEF08

- *A.B.G.M. Leferink op Reinink,; E. van den Pol; A.V. Petukhov, G.J. Vroege; H.N.W. Lekkerkerker*, Phase behaviour of lyotropic liquid crystals in external fields and confinement, European Physical Journal-Special Topics 2013, 222, 3053-3069.
- *A.B.G.M. Leferink op Reinink, S. Belli; R. van Roij, M. Dijkstra; A.V. Petukhov,; G.J. Vroege*, Tuning biaxiality of nematic phases of board-like colloids by an external magnetic field, Soft Matter, 10, 446-456, 2014.
- *A.B.G.M. Leferink op Reinink*, Colloidal Mineral Liquid Crystals: Formation and Manipulation. PhD thesis, Utrecht University, 2014.

5. Valorisation and outreach

This has from the start been a programme focused on fundamental research. Nevertheless, contributions to neighbouring fields have been made, e.g. by co-organizing PhD schools with the fields of 'peloids' and the field of 'granular matter'. In addition, all schools and international symposia were open the others outside of the programme and SFB. See also the website and newsletters as part of outreach activities: **www.codef.de**.

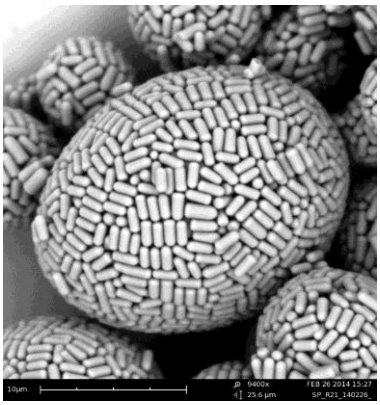


Figure: Supraball obtained by self assembly of fluorescent silica rods (length 2 μm) in a spherical confinement by drying an emulsion droplet (Bing Liu, bar 10 μm).

Based on [6], see above first list, FOM has written a **press release**, which was picked up by *de Volkskrant*.

APPROVED DFG/FOM PROGRAMME

Number	61.
Title (code)	Physics of colloidal dispersions in external fields (CDEF)
Executive organisational unit	BUW
Programme management	Prof.dr. A. van Blaaderen
Duration	2002-2015
Cost estimate	M€ 2.1 (FOM part)

Concise programme description

a. Objectives

The major goal is a 'microscopic' understanding - on the basic time and length scales - of colloidal dispersions under external control. In doing so a systematic development of theoretical approaches, new simulation techniques and experiments in non-equilibrium is necessary, which focus on the essential physics of the samples and thereby reveal the principles of the external perturbation.

b. Background, relevance and implementation

Examples for soft matter systems, which comprise at least one structural length scale in the mesoscopic regime between a micrometer and a nanometer, include quite different classes of materials such as colloidal dispersions, polymers, membranes and biological macromolecules. These systems are 'soft' as they react much more sensitively to mechanical perturbations (such as shear) as compared to pure molecular materials. The research activities in the field of soft matter are interdisciplinary and have exhibited a rapid growth and strong diversification. Therefore, a focus on an important part of the whole soft matter realm of research activity is reasonable and necessary, while at the same time maintaining an open view with respect to the interdisciplinary circumstances and the technical applications. In this DFG/FOM programme we focus on the rich physics of colloidal dispersions, under external control (shear, electric, laser-optical and magnetic fields and confined geometrics). The latter are solutions of mesoscopic solid particles with a stable (i.e. non-fluctuating) core embedded in a molecular fluid solvent. Among the various soft matter systems, colloidal dispersions play a prominent role as they can be both prepared and characterised in *a controlled way*. The effective interaction between the colloidal particles can be tailored by changing, e.g., the salt concentration in the solvent. Moreover, colloidal suspensions can be regarded as the simplest prototype of soft matter: the length scale separation between the molecular solvent and the mesoscopic particles is unique and complete. Spherical particles without any additional structure on the mesoscopic length scale possess the simplest and highest possible symmetry. This directly implies that a simple theoretical modelling of a single particle without many fitting parameters is possible. Exciting questions concern collective many-body effects

induced by cooperation and self-organisation of many particles. A striking advantage of colloidal dispersions lies in the fact that these questions can be studied simultaneously by using three different complementary methods, namely *experiment, computer simulation, and theory*. This can be demonstrated using three examples where considerable achievements have been made in the past, namely the bulk freezing transition, the kinetic glass transition and the investigation of crystal nucleation rates.

Funding

salarispeil cao per 01-07-2012

bedragen in k€	≤ 2013	2014	2015	2016	2017	2018	≥ 2019	Totaal
FOM-basisexploitatie	1.917	-	-	-	-	-	-	1.917
FOM-basisinvesteringen	133	-	-	-	-	-	-	133
Doelsubsidies NWO	-	-	-	-	-	-	-	-
Doelsubsidies derden	-	-	-	-	-	-	-	-
Totaal	2.050	-	-	-	-	-	-	2.050

Source documents and progress control

a) Original programme proposal: FOM-02.0759
b) Ex ante evaluation: FOM-02.1233
c) Decision Executive Board: FOM-02.1395
d) Mid-term self-evaluation report: FOM-05.0946
e) Mid-term review: FOM-05.0877
f) Decision Executive Board: FOM-05.0876/D + FOM-08.1062
g) Mid-term review: FOM-09.0937
h) Decision Executive Board: FOM-09.0936/D

Remarks

The programme concerns the FOM contribution to a joint German/Dutch collaboration in a so-called 'Transregio-sonderforschungs-bereich' with the same title. Mid-term evaluations were held in the Spring of 2005 and 2009.
The final evaluation of this programme will consist of a self-evaluation initiated by the programme leader and is foreseen in 2015.

DK par. HOZB

Subgebied: 100% COMOP

Historical overview of input en output

Input	personnel (in fte)				finances* (in k€)
	WP/V	WP/T	PhD	NWP	
2003	p.m.	p.m.	p.m.	p.m.	88
2004	p.m.	p.m.	p.m.	p.m.	139
2005	p.m.	p.m.	p.m.	p.m.	101
2006	-	-	3,1	-	142
2007	-	1.0	3.5	-	280
2008	-	1.0	2.0	-	143
2009	-	-	2.1	-	145
2010	-	0.1	2.5	-	246
2011	-	1.0	2.2	-	161
2012	-	1.0	2.0	-	164
2013	-	0.9	2.0	-	228

Output	PhD theses	refereed publications	other publications & presentations	patents
2003	-	-	-	-
2004	-	-	-	-
2005	-	6	12	-
2006	-	5	7	2
2007	1	9	10	-
2008	1	15	32	-
2009	-	3	14	-
2010	-	13	29	-
2011	-	2	8	-
2012	-	6	13	-
2013	-	4	6	-

* After closing the financial year.

PhD defences

2007
Yu Ling Wu, 16 May 2007, FOM-U-09.
2009
None.
2011
None.
2013
None.

2008
Volkert de Villeneuve, 19 March 2008, FOM-U-06.
2010
None.
2012
None.

Patents (new/changes)

2013

None.

Overview of projects and personnel

Workgroup FOM-U-06

Leader	Prof.dr. H.N.W. Lekkerkerker
Organisation	Utrecht University
Project leaders	Dr. G.J. Vroege
	Dr. A.V. Petukhov
Programme	Physics of colloidal dispersions in external fields
Project (title + number)	Structure formation in columnar mineral liquid crystals in confinement 09CDEF08

FOM employees on this project

Name	Position	Start date	End date
A.B.G.M. Leferink op Reinink	PhD	15 November 2009	14 November 2013

Workgroup FOM-U-09

Leader	Prof.dr. A. van Blaaderen
Organisation	Utrecht University
Project leader	Dr. A. Imhof
Programme	Physics of colloidal dispersions in external fields
Project (title + number)	Phase transitions of confined nanorods in electric fields 09CDEF07

FOM employees on this project

Name	Position	Start date	End date
B. Liu	postdoc	01 December 2010	30 November 2013
T. Troppenz	PhD	07 September 2010	06 September 2014