ESF Exploratory Workshop on

Frontiers in European Research on Liquid Crystalline Soft Matter

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LC Lab, Bandol

France

Scientific Report by:

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EUROPEAN SCIENCE FOUNDATION

SETTING SCIENCE AGENDAS FOR EUROPE

Exploratory Workshop Scheme

Standing Committee for Life, Earth and Environmental Sciences (LESC)

Standing Committee for Physical and Engineering Sciences (PESC)

Workshop web site: www.workshop.lcsoftmatter.com

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Executive Summary

Main objectives

1. To obtain an overview of current innovative European research in the realm of soft condensed matter that addresses, applies or relies on aspects of the liquid crystalline state of matter and its formation processes,
2. to bring together a small group of leading European scientists representative of different sub-disciplines of soft matter research where liquid crystallinity plays a role, thereby cross-fertilising activities which so far are often not as much in contact as could be beneficial,
3. to sow the first seeds for new European research networks on strategically relevant topics in the field, and to distinguish those with the best prospects of producing a valuable contribution to society, addressing issues relevant to e.g. health, energy, advanced technologies etc.,
4. to contribute to the definition of a 'road map' for focused future development of European research on liquid crystalline soft matter, taking academic as well as industrial perspectives into account, thereby strengthening Europe´s position in this rapidly growing multidisciplinary research field.

Workshop components

1. Scientific Research Presentations

Sharing of expertise (contributing to objectives 1 and 2)

2. Research Network Discussions

Identifying topics benefiting from collaboration (objective 3)

3. Summaries and Strategic Discussions

Recognising target activities (objective 4)

Workshop participants

The workshop comprised 24 invited participants (one was in the last minute prevented to attend for personal reasons) and 2 organisers, representing eight different European countries (France, Germany, Italy, The Netherlands, Poland, Slovenia, Sweden, United Kingdom). Each invited participant contributed with a scientific presentation. Six of the speakers in the final program were women and another was included in the next-to-final program but unfortunately had to announce her unavailability one week prior to the workshop. These two constellations corresponded to 28% and 25% female representation among the invitees, respectively. As for age, the final constellation had an 8%/75%/17% distribution of young/mid-career/senior contributors. One observer (Dr. Victoria Cleave) from the journal *Nature Materials* attended the full workshop and the ESF *rapporteur* Prof. Kenneth Ruud was present from the afternoon of day two.

Report publication and dissemination of results

Apart from this report, scientific reports on the workshop are being published in the journals *Nature Materials* (report author: Prof. R. Stannarius), *ChemPhysChem* (Prof. P. van der Schoot), *Europhysics News* (Dr. G. Scalia) and *Liquid Crystals Today* (Dr. M. Mitov). Among these, reports 1 and 4 have been submitted and approved by

the respective journals, and 2 and 3 will be submitted in August. In addition, the workshop web site (www.workshop.lcsoftmatter.com) will remain on-line and may be used for posting reports that should be accessible to the general public. At present the program and all abstracts are available for download.

Summary of scientific content

The workshop comprised five thematic sessions devoted to:

- Liquid crystals in and from living matter and in medicine,
- Drops, bubbles, tubes, foams and films,
- Colloidal liquid crystals and liquid crystal colloids,
- Liquid crystals for new functional materials, organic electronics and photovoltaics,
- Liquid crystals in sensors, actuators and novel optic and electrooptic devices.

The excellent presentations made it very clear that Europe holds cutting-edge researchers dealing with liquid crystal-related soft matter, their work being at the very forefront of the field. In line with the intentions of the workshop, the presentations also demonstrated the vast field of relevance of liquid crystals, well beyond the traditional realm of electrooptic devices like displays. Examples from the workshop program that appear as strategically important modern fields are liquid crystal phase formation of DNA, both naturally in e.g. viruses and synthetically in experiments with ultrashort DNA chains (which may well have a bearing on the origin of life); geometries and singularities known from the study of liquid crystals being recognised in living creatures; fluid yet ordered lipid structures playing key roles in nano- and microfluidics as well as drug delivery; controlled positioning and alignment of colloidal micro- and nanoparticles in liquid crystals; liquid crystal phases formed by mineral nanorods or -discs; highly compartmentalised structures with potential for new functionalities formed via liquid crystalline self-organisation; enhancement of organic semiconductors by means of liquid crystal-directed ordering; and light- or heat-stimulated actuators derived from liquid crystalline elastomers.

As a result of the speakers representing complementary expertise and sometimes different main communities, discussions were very lively, with constructive, inspiring and sometimes highly original comments and suggestions being brought forward. The attendants expressed great enthusiasm for the meeting and pointed out that their research horizons had been broadened and enriched.

Output in terms of future European research collaborations

The meeting clearly paved the way for several future European collaborations, potentially breaking totally new ground. As several participants expressed their appreciation of having made new contacts on a person-to-person basis, the chances that a number of new bi- or trilateral collaborations will result from the workshop is very high. In addition, the general discussions as well as those focused on large-scale European initiatives led to the identification of six themes that would be suitable for future research networks. The discussions around two of these (*Micro- and nanoparticles in liquid crystals* and *Liquid crystal elastomers & polymer-stabilization techniques*, respectively) have already advanced quite well, both considered as being at the core of a coming ESF Research Networking Program proposal. Considering that we are currently in vacation times there is good reason to believe that the discussions around the other themes will get more active in the autumn.

A restricted section of the web site, with access only for workshop participants, has been prepared, where each participant can download presentations from the meeting (a few participants were unable to upload their presentations for priority reasons), provide concise summaries of their research interests, expertise and facilities, as well as continue discussions about future research networks on-line.

Scientific content

The workshop program comprised three days. In the opening session the organisers addressed the scientific motivation for this kind of meeting and stressed the important features of the program: every topical session starts with a keynote lecture and ends with a summarizing discussion. There was also one brainstorming session at the end of each day, as well as an ESF information session at the end of the second day. They also briefly traced the history of the meeting venue, the LC Lab Bandol. The laboratory was inaugurated in 1987, its first EU scientific meeting was held in 1992, followed by a number of research symposia and a summer school mainly addressed to PhD students every September since 2006.

Session 1

The Keynote speaker of the first session (*Liquid crystals in and from living matter and in medicine*) was Françoise Livolant from University of Paris-Sud in Orsay, who reported on bacteriophages (viruses infecting bacteria by injecting their DNA) and the different long-range ordered (or disordered) structures of their DNA inside the capsid, before as well as during ejection. The Livolant team used cryo electron microscopy to study the organisation of the DNA at various stages of the ejection from the virus capsid ("head"), a protective protein shell of icosahedral symmetry. It was thereby possible to discern no less than four different phase structures formed by the DNA: orthorombic crystal, hexagonal (2D) columnar liquid crystal, chiral nematic liquid crystal and isotropic phase. As most of the physicists and chemists in the audience did not have the speaker's biology background, their immediate interest in the subject led to frequent interruptions and a most lively discussion arose which set the atmosphere for all succeeding presentations.

DNA liquid crystals were also the subject (together with RNA) of the presentation by Tommaso Bellini from the University of Milan. In this case the nucleic acids considered were short synthetic duplexes which display a surprisingly strong tendency to order (self-organise) in chiral nematic (cholesteric) or columnar phases. The lecturer also reminded us of how the structure of DNA was originally deciphered: It was Rosalind Franklin who first succeeded in making hydrated DNA that orders into the nematic phase. Her X-ray picture from this phase disclosed clearly the double-helix structure for Crick and Watson.

Yves Bouligand from University of Angers continued the exposition with many examples from the living world focusing on the defect structures that disclose the micro-organisation of biopolymers as in beetle and crab shells, in collagen and in the skin of many invertebrates.

The "living" session concluded with a presentation by Katarina Edwards from University of Uppsala dealing with medical usage of lipid/surfactant model membrane structures for targeted delivery of radioactive or chemotherapeutical substances. The aim of the work, which has already reached clinical tests, is cancer treatment: the substances are to be released directly to specific organs or cells where they result in DNA breakdown and death of the cancer cell. A new approach of her team is to use bilayer disks rather than spherical liposomes as carrier vehicles, thereby avoiding certain problems with the latter vehicles such as the tendency towards aggregation into bulk lamellar liquid crystal phases (a consequence of the fact that liposomes

of natural lipids are non-equilibrium structures). This is a very lively area of applied lyotropic liquid crystal-like structures in medicine where one of the outstanding problems is to attach the right targeting agent onto the surface of the vehicle membrane in order to tailor it for the receptor of a specific tumour cell.

Session 2

The keynote lecture to the session *Drops, bubbles, tubes, foams and films* was given by David Quéré from ESPCI and École Polytechnique, Paris. Starting with the question of how a liquid drop interacts with a surface—wetting or non-wetting—depending on the real area of contact (and to some extent the hydrophobicity of the surface) one soon arrives at applications of wide practical interest, such as car, boat and airplane windshields which are not wetted by rain. Nature has already solved this problem. The lotus effect is well known (water drops on a lotus leaf just roll off) and is due to the nano-structured leaf surface with small spikes sufficiently close to each other that the real contact surface is very small. Insect eyes like in mosquitos cannot be wetted either, for the same reason, they are anti-fogging. For human society-related applications this becomes an engineering problem: we cannot only mimic the structures found in nature, the materials must also be very robust and resistant to wear.

The following talk by Ralf Stannarius from the University of Magdeburg discussed bubbles and films but not made from soap and water but by smectic thermotropic liquid crystals. While it is not possible to have a "one-dimensional liquid" (a liquid string disrupts, forming drops) certain liquid crystals do permit 'strings' (or filaments) with a cylindrical internal structure to form. There are otherwise many analogies between liquid crystal films and soap films and bubbles, the study of which essentially goes back to Lord Raleigh. This is so far pure basic research but ideas of applications will certainly come up—as always—with time.

The use of nano-patterning was also the subject of the talk by Owe Orwar from Chalmers. Using the Marangoni effect (mass transfer in a liquid layer due to surface tension differences—also involved in the "wine tear" phenomenon in a wine glass) his team moves monolayer lipid films on a nano-patterned surface in a controlled way. The resulting nanofluidic system allows one to reduce the dimensionality of classic reaction chemistry to 2D and even 1D. Also Robert Hołyst studied monolayers, but in his case thermotropic smectic C layers on a water surface, which permits him to observe collective rotations on all scales, giving rise to self-similar patterns. He also showed experiments with carbon nanotube (CNT) suspensions in aqueous surfactant solutions, were phase separation was induced by adding a hydrophilic polymer that acts as depletant. The CNTs were then collected in a surfactant-rich upper phase that exhibited hexagonal liquid crystalline order.

The last talk of the session was by Ulf Olsson, University of Lund, who gave an account of the very strange phenomenon that lamellar lyotropic liquid crystals can form multi-lamellar vesicles ("onions") when subject to shear. It has been demonstrated very clearly by both small-angle light scattering and neutron scattering. Moreover, this transition is reversible which has been confirmed by spatially resolved NMR-imaging. Nobody can explain this striking phenomenon, which shows that there still is a fundamental gap in the understanding of the dynamics of lyotropic liquid crystals. It was left as a challenge to the present theoreticians.

Session 3

The session *Liquid crystal colloids and colloid liquid crystals* opened with Igor Muševič from University of Ljubljana giving an overview of the exciting phenomena observed when you disperse colloidal particles in a nematic liquid crystal. The particles in this case are most often spherical inclusions such as droplets, but could also be rodlike. The long-range anisotropic forces between the particles turn out to be extremely strong (on the

order of 1000 *kT* to 3000 *kT*) and give rise to formation of chains and 2D assemblies which cannot be observed with isotropic solvents. In these 1D- and 2D-structures the interaction is mediated by topological defects, sometimes even by entangled singular lines. The forces, attractive or repulsive, are found by considering the deformations in the director-field. By optical tweezers the particles can be organized and reorganized at will. In this way a 2D photonic crystal can be made. An obvious but non-trivial task is of course to proceed to 3D photonic crystals. So far tunable micro-resonators have been achieved in this way.

In the following talk, by Giusy Scalia of ENEA, Naples, a particular type of rodlike inclusion, namely carbon nanotubes, were studied. In this case the most urgent problem is to hinder the CNTs to clog and bundle into disorganized aggregates in which their extreme one-dimensional characteristics cannot be used. In order to align them they have been dispersed in thermotropic as well as in lyotropic nematic liquid crystals. Their alignment can be monitored by Raman scattering measurements. A very interesting but highly complex question is what regulates whether carbon nanotubes can themselves form a nematic phase according to the Onsager concepts. The challenge is to achieve very high nanotube concentration without substantial bundling. This discussion was taken up by Chistoph Blanc from University of Montpellier, concluding that multi-wall tubes more commonly form nematic phases than single-wall tubes. He also reported on good progress in achieving carbon nanotube-polymer composites in which the tubes remain individualised. Here DNA reentered the discussion, but now in the role as one of the best molecules available for dispersing carbon nanotubes.

The nematic-isotropic phase transition is first order, hence both phases can coexist at the transition. Recent experimental studies of the coexisting phases in contact with a solid vertical wall has prompted Paul van der Schoot from Eindhoven University of Technology to study the geometrical situation from a theoretical point of view. The nematic phase considered is a lyotropic suspension of disc-like colloidal platelets of the inorganic mineral Gibbsite (α-$Al(OH)_3$) in water. The meniscus between the isotropic and nematic phases (the former is on top of the latter) rises in a peculiar non-monotonic way that depends on the orientation of the director field relative to the solid and liquid surface. Comparison with experimental data yield the anchoring strength as well as the surface tension of the nematic.

Another inorganic mineral, Goethite (α-FeOOH) was the main constituent studied in the last contribution of the session. It forms board-like crystal flakes of typically 200 by 40 by 20 μm^3 dimension and can be stabilized electrostatically in water of pH around 3. Dispersions of such flakes show the richest phase behavior so far found in mineral liquid crystals, they exhibit isotropic, nematic, columnar and even the smectic A phase. Both the nematic and the smectic A may be biaxial (this depends on the polydispersity), hence there may be a direct biaxial nematic-isotropic transition. Because the crystal platelets are themselves antiferromagnetic, phase transitions can also be induced by varying an external magnetic field. These clay-like minerals are of course very unconventional forms of liquid crystal and they point to a completely new area of interest. An intriguing question put forward by one of the fascinated non-specialists in the audience was if one can contemplate a relation between smectoid structures of this type and landslides.

Session 4

The session *Liquid crystals for new functional materials, organic electronics and photovoltaics* was introduced by Carsten Tschierske from University of Halle-Wittenberg who is one the world's leading synthetic chemists working with liquid crystals, developing new and unconventional molecular structures that self-organise in new liquid crystal forms. The polyphilic mesogenic molecules are designed with different incompatible parts interacting in a way that would not permit assembly in orthodox nematic or smectic form. This leads to

amphiphilic and shape-dependent self-assembly giving honeycomb-like arrays of triangular, square, pentagonal or hexagonal cylinders and periodic packings combining different forms of cylinder. One finds, in particular, a rich variety of structures that could be designated 2D crystals, and even 3D crystals. However, like the blue phases and the lyotropic 3D liquid crystals (bicontinuous 3D structures) they share the property that they are *locally liquid*. This is a property also characteristic of rubber. As pointed out, the concept has an almost limitless potential in designing new complex soft matter structures whose functional properties can be very interesting.

An example of a very goal-focused approach to organic electronics using (in principle) existing techniques was described in the following talk by Mary O'Neill from University of Hull. Her group's approach to nematic organic semiconductors for OLEDs, organic solar cells (photovoltaics), field effect transistors and plastic electronics in general starts with very long nematogens based on thiophene (14 aromatic rings in a row) with a diene end group for later crosslinking. The nematic order parameter measured in the glassy state is extremely high (S = 0.92). A fluorine part is incorporated as light emitter. As electron donor the thiophene material is deposited by spin-coating after which it is crosslinked by illumination with UV light. The same procedure is performed with the electron acceptor material. The crosslinking gives insoluble films and the high nematic order gives improved carrier transport and polarised electroluminescence. The deposited films are indeed nematic glasses at room temperature (their glass transition temperature is 39°C). This project has demonstrated good prototypes and is close to industrial application.

Claudio Zannoni from University of Bologna then delivered a review of the current simulation results and techniques, a topic of basic importance to fundamental soft matter science but also recently more and more accessible to device applications. With increasing computer power surprisingly precise predictions can now be made which were not thought to be possible only ten years ago. For instance, it was considered impossible to predict phase transitions and order parameters. A striking example of success are the simulations for the industrially important family of cyanobiphenyls, *n*CB, which were able to reproduce, in remarkable detail, both phase sequences and transition temperatures as a function of the length (n) of the end chain, and even the order parameter as a function of temperature. Another success story are the Monte Carlo calculations of equilibrium defect structures in nematics as well as the recent (2009) modelling of nematic display dynamics at a molecular level.

A cholesteric liquid crystal has the unique optical property of selectively reflecting light within a bandgap Δnp around the wavelength $\lambda = np$, where p is the helical pitch and n and Δn are the average index of refraction and the index difference along and perpendicular to the local director, respectively. The reflected light is circularly polarised with the same handedness as the cholesteric helix, the other half of opposite handedness being transmitted. At normal incidence a cholesteric thus never reflects more than 50% of the ambient light. There has, since the discovery of the phenomenon, existed a desire to somehow increase the reflectivity beyond the 50% limit, in order to obtain a more ideal reflector, so far with limited success. In the approach of Michel Mitov and his group at CNRS in Toulouse the reflection band is broadened by introducing a gradient in the pitch of a polymer-stabilised cholesteric. The reflectivity is also increased by interlacing layers of inverse helicities. Again nature has solved this problem in the rare case of the "golden beetle" (*plusiotis resplendens*) where a non-chiral tissue corresponding to a $\lambda/2$ plate is inserted between two cholesteric tissue parts of the same handedness. Could it be possible to mimic nature also in this manufacturing process?

The last talk of the session was devoted to a subclass of smectic liquid crystals that may open an interesting road to chirality detectors, desirable for instance in pharmaceutical industry and medicine, but likewise of interest for very fast displays. Frank Gießelmann from University of Stuttgart started with the recent finding that

polydispersity (broad distribution in the length of the molecules) must not promote the nematic phase at the cost of smectic phase, but it could be the other way around. Although this is very counterintuitive, the effect turned out to have been predicted already in 1989 (by T. Sluckin). This theory together with the new experimental results increase our understanding of systems forming smectic phases with unusually low nematic order parameter, one of the hottest topics in today's thermotropic liquid crystal materials development research. It has a wide range of forthcoming applications, not least in connection with many topics of the following session.

Session 5

The last session, *Liquid crystals in sensors, actuators and novel optic and electro-optic devices*, was introduced by the keynote presentation of Mark Warner, Cavendish Laboratory, Cambridge, on the topic of ferroelectric smectic C* elastomers. Such elastomers combine properties found in classical rubber—polymer chains whose distribution can be distorted by a stretch to a lower entropy state—with the anisotropy of the liquid crystal, and a local spontaneous polarisation due to the reduced symmetry of of chiral smectic C (C*). They are the most complex elastomers so far synthesised and also the richest in application potential. Their very complicated physics is fairly well understood theoretically but applied work has been strikingly limited, mainly due to the scarce availability of material. It is tedious to manufacture and, so far, there has essentially been only one source, the macromolecular chemistry institute in Freiburg, Germany. Already a nematic elastomer (crosslinked nematic polymer) shows one of the unique characteristic effects: a dilatation perpendicular to the director **n** causes **n** to rotate rather than broaden the chain distribution around **n**. In a smectic C* elastomer this rotation is more complicated but it can now also be performed by an applied electric field. The helix characteristic of tilted chiral smectics can be avoided in the elastomer because the crosslinking can be performed at higher temperatures, when the material is in the non-tilted and thus non-helical smectic A* phase.

Crosslinking effects applied to monomeric liquid crystals have been studied by Ingo Dierking from Manchester University. By adding a small percentage (< 10%) of photoreactive monomer to a liquid crystal host the characteristic phase anisotropy can be stabilised during the subsequent photopolymerisation. The result is a bicontinuous structure called polymer-stabilised liquid crystal and the technique is rapidly developing into a routine process for many applications. For instance, it will improve the mechanical properties and increase the thermal stability range of the optically very attractive but normally very delicate defect-rich blue phases. As the polymer network adopts to the director field, this field is "frozen in" with all its characteristic defects, and it is this effect that stabilises the blue phase structure. The networks can also be studied by scanning electron microscopy, which directly confirms the structure around such defects (even in the complicated case of a twist grain boundary phase), features that have previously been deduced only by indirect methods.

The presentation of Per Rudquist from Chalmers University of Technology dealt with the subtle balance between the two main chiral tilted smectic phases and how they are influenced by confining surfaces, making adequate surface treatment a critical issue for many application concepts. With the right choice of surface and cell thickness a tristable device can be obtained where the two field-induced (ferroelectric) states have essentially the same energy as the (antiferroelectric) ground state. Such a device has potential for several new interesting applications, in particular if high-optical-tilt materials (so-called 'orthoconic' antiferroelectric LCs) are used.

The concluding talk of the workshop was delivered by Helen Gleeson (Manchester University), currently vice president of the International Liquid Crystal Society. The presentation dealt with smectic systems related to those discussed in the previous talk as well as with biaxial thermotropic nematics. In the first case resonant x-ray scattering and electrooptic measurements were employed to investigate the two intermediate phases (often

called “subphases”) that have structures frustrated between those of the more common smectic C* and smectic C_a*. In the second part an attempt to employ Raman scattering for confirming whether or not the nematic phase formed by certain new thermotropic materials is biaxial was described. While the intermediate phases are unlikely to be useful in applications the possibility of applying a biaxial thermotropic nematic has the last few years made the search for such materials a hot topic. As the speaker pointed out, in 2003 one LCD had been sold for every person on earth, and in 2008 LCD TV became the leading technology (>50% of the 200 million TVs shipped). In spite of the natural fact that the academic input to this market has been considerably reduced in recent years the LCD-TV manufacturers are still looking for new technologies that could enhance the performance. It has been suggested that one of these may be based on thermotropic biaxial nematics. The presentation however confirmed that those materials presently considered as candidates have such weak biaxiality (if indeed any at all) that already its confirmation is a very delicate matter. An application in a device still seems very far away.

Assessment of results, contribution to future directions

Scientific results

Two prime scientific aims of the meeting were (1) to demonstrate the full breadth of the research field of soft matter systems where the spontaneous development of long-range order plays a role (i.e. liquid crystalline soft matter), in the process highlighting some examples of cutting-edge European efforts from various sub fields, and (2) to cross-fertilise communities that do not regularly meet, yet share a fundamental interest in the research field, by providing an opportunity for scientists from these communities to meet, discuss and get inspired by each other. We can state with certainty that both these aims were met very well in the workshop, throughout which a genuinely friendly and constructive atmosphere prevailed.

The research presentations were on a very high level and covered topics from viruses, DNA and cancer therapy to actuators, displays, organic electronics and photonic devices, via colloids, fluid dynamics and computer simulations. The very lively discussions, during and in between sessions, clearly demonstrated that the speakers generally succeeded in conveying their results to colleagues with somewhat different expertise, but also that they in their role as listeners found a stimulating input from researchers they don't regularly listen to or read articles by. This view was also expressed explicitly by several participants, in public as well as directly to the organisers. One speaker summarised the situation very well with the words "I really appreciate being part of this workshop because I have rarely been at a scientific meeting where I have known so few of the other participants". Yet, this did not mean that he felt alienated or uninvolved. On the contrary, he was very active in the discussions, as were indeed most participants.

Although the very broad scope of the meeting made it challenging to attend, since few or no persons have a deep understanding reaching across all topics covered, it also led to a strong enrichment and expansion of the attendants' awareness of research on liquid crystalline soft matter. Moreover, several cross-over points between the different European soft matter research activities represented could be identified. Much inspiration for new research thrusts can be gathered from being served a 'smörgåsbord' of fascinating science as rich as that created by the speakers, hence we believe the prospects are good that the meeting will have served as a foundation for diverse future European initiatives for state-of-the-art academic research in the field.

Networking

Because many researchers met each other for the first time and were relatively new to at least some aspects covered in the meeting, it was decided that the first two of the brainstorming sessions aimed at network initiatives should be uncoordinated. This gave the participants the opportunity to discuss freely person-to-person, asking questions about talks that they perhaps did not wish to bring up in public, and let smaller discussion constellations spontaneously form and dissolve. The terrace and garden of the meeting venue provided just the right setting for such self-organised discussions and these were indeed very lively and

constructive. Several attendants expressed their appreciation of these discussions after the meeting, pointing out that many new ideas for bilateral collaborations came out of them.

At the start of the third day, however, it was felt that the time was ripe for more structured discussions around large-scale networks and suggestions for suitable topics were thus collected throughout the day, which then formed the basis for a division in smaller focused groups in the final brainstorming session. As a result, six themes were defined as possible topics of future networks:

- Hierarchical liquid crystal organisation (self-organised order on multiple length scales)
- Micro- and nanoparticles in liquid crystals
- Chiral liquid crystals with structural gradients
- Liquid crystal elastomers and polymer-stabilisation techniques
- Biosensors
- Biaxial nematics and the control of their alignment

As several researchers had an interest in more than one of these topics, it was deemed undesirable to divide into six groups for discussing all of them in one session. Instead the second and the fourth were chosen as initial discussion topics and two groups of roughly equal size met in different places to discuss the forms under which these topics could be addressed via a European initiative. The remaining topics were to be the topics of continued post-workshop on-line discussions (see below).

The topic *Micro- and nanoparticles in liquid crystals* attracted many interested partners, largely because it is actually a very broad topic in itself. During the discussions it quickly became clear that several aspects may be worth a focus, many alternatives being brought up in terms of which kind of particles could be considered (e.g. carbon nanotubes, gold/silver nanorods, micron-size silica or polymer particles, ferroelectric and ferromagnetic nanoparticles), the general motivation (generation of new properties, alignment or other types of large-scale organisation of particles, fundamental physics and chemistry dictating the interactions between guests and host) as well as the more practical issues to address (dispersion, characterisation, identification of optimal liquid crystal hosts). The group therefore concluded that Seventh Framework programs such as STREP or Marie Curie Actions would require a separation into smaller subgroups with more specialised foci, as they are unlikely to work out if the starting group is too large, too broad and with partners without obvious roles in the network. Instead, an ESF Research Networking Programme initiative was identified as suitable for addressing the topic in its full breadth, since the flexibility of this framework allows for various sub-topics being dynamically addressed in e.g. workshops and smaller meetings. The plans are to formulate a proposal on Micro- and nanoparticles in liquid crystals (this tentative title is likely to be somewhat adjusted during the process) for the current call and the workshop convenor, Jan Lagerwall, offered to coordinate this effort (time permitting). More focused proposals for e.g. Marie Curie actions are likely to develop as well, either in parallel to the Research Networking Programme initiative or as a result of it.

During this discussion the need for a richer presentation of each partner, where expertise, interests and facilities are summarised in writing, was identified. We have therefore created a “Researcher Summaries” page in the restricted section of the workshop web site where each participant of the workshop can present her-/himself and the research group that s/he represents, as well as what the participant seeks in future collaborations and what s/he can contribute with. In addition, the restricted section of the web site also holds many of the presentations from the meeting as well as a discussion forum for each of the six identified network topics. Here the initiated discussions can continue on-line and discussions on topics not yet addressed deeply have a framework for developing.

So far, the usage of these tools (which obviously are not restricted to the discussion group suggesting their creation) is not very strong but one must take into consideration that vacation time followed soon after the workshop. We thus believe that the activity will intensify in the autumn when people are back in their regular working schedule and also have had time to contemplate the new impressions given during the workshop and formulate more stringent ideas for joint initiatives.

In the discussions on *Liquid crystal elastomers and polymer-stabilisation techniques* Prof. Mark Warner took a leading initiative, which was natural considering that he is one of the main authorities in the field, world-wide. He kindly provided the organisers with his notes for incorporation into this report, and these are given in condensed form in the following, together with some additions by the authors.

Polymeric networks of a spectrum of types—elastomers, high modulus glasses, polymer dispersed liquid crystals, polymer stabilized liquid crystals, ...—were identified as a priority that engages several participants. Although very different systems, they have in common that they are responsive to fields and stimuli such as heat, light, electric and magnetic fields, or solvent addition, and are interesting in nematic, cholesteric, and smectic phases. Both thermotropic and lyotropic networks are relevant. The interests of the participants (and other contacts spoken to since the meeting) include:

- Mechanical response for actuation, sensing, changes of surface topography (for optics, printing), micro-fluidics, medical diagnostics, changes of photonic structure, dynamic mechanical applications (e.g. damping), and energy (light and heat) harvesting,
- Optical and photonic properties in soft, responsive materials—e.g. cavityless rubber lasers, bistable electrically-driven SmC* films, solid super-reflectors made from cholesteric networks (and adaptive versions of the above),
- Structured LC solids, for instance smectic networks of complex mesogens with nano-pores and channels (e.g. for separation), cholesteric gels for separation of chiral enantiomers from racemic solvents.

A wide range of new intriguing physical phenomena have been discovered, combining LC properties with those of responsive solids, and unusual types of activation have been identified, mainly thermal, photonic and electric, with the latter two being the most promising. The next steps were envisaged to be where fundamental science went together with development of devices and new technology, requiring the involvement of engineers and mathematicians, experts in existing LC areas, experts in mechanics and optics, as well as chemists capable and willing to synthesise the required materials. In particular the latter aspect calls for new forces entering the field as the group of Prof. Heino Finkelmann (Freiburg, Germany), which has long dominated the field, will cease activities as a result of its leader's retirement in Feb. 2010. Also ways of linking new synthesis centres to physics and applications teams need to be created. As already pointed out, the helix typical of chiral tilted smectics can be avoided by crosslinking in the smectic A* state. Thus an orthoconic antiferroelectric (see above) could be envisaged in elastomer form. This would be a truly remarkable material with unique mechano-optic as well as electro-optic properties. Nobody has so far considered this challenge (the orthoconic smectics are a fairly recent discovery).

In addition to liquid crystal elastomers, another liquid crystal polymer topic of interest for future networks is polymer stabilisation of liquid crystals. This is of great applicative interest as it can be used e.g. to improve the mechanical properties of ferroelectric devices or to speed up the back relaxation in antiferroelectric ones. A fundamental problem which needs to be addressed is light scattering from polymer chain bundles. While such light scattering does not always occur the understanding of the phenomenon is not yet satisfactory. A thorough investigation of the process and how it can be minimised/avoided should thus be an important topic. Likewise,

the possibilities of tuning the host phase by the polymerisation process are worthwhile further studies. The polymerisation can strongly affect the electro-optic switching properties, for instance changing a bistable (strongly nonlinear) ferroelectric device, switching between two stable states, to a monostable device showing a continuous, more or less linear response to an applied field.

So far, the discussions around elastomers and polymer stabilisation were conducted within the framework of a single initiative, but it may be more strategically relevant to split these topics. They are both very broad and have vast application potential. Applications for resources to either the ESF or the EU were both considered, the right choice again depending on the size of the constellation. Initial application to ESF for Research Networking Programme meetings could foster collaboration among a large community. Meetings could be held e.g. in Cambridge since (a) nearby London/Stansted is a major hub for budget airlines (b) accommodation/meeting space is easy to organise out of teaching terms.

Further strategic considerations

Two fields that emerged as highly fertile for coming European network initiatives, yet were not among the six identified discussion topics, are *liquid crystals in biology* and *liquid crystals for organic electronics and photovoltaics*. The first of these was well represented at the workshop but unfortunately due to collisions with other scientific meetings and to the railway strikes in France a few key speakers for this topic could not attend the discussions on Friday afternoon, leading to its absence in these discussions. In order not to loose good opportunities for European research networks in this field it may be worthwhile to organise a smaller follow-up meeting devoted solely to this subject.

The second topic was regrettably underrepresented at the workshop, not only in relation to its scientific potential but also regarding the European perspective; European activities in this field are currently very strong. In part, the under-representation of the field at the workshop was a result of the boundary conditions dictating the participant list (the number of invited German researchers was restricted to four by ESF rules because the organiser was from a German institution, and the wish to have strong presence of female and young researchers unwillingly led to a stronger emphasis on other fields). A smaller meeting dedicated to this emerging and technologically very important use of liquid crystals may also be a very good follow-up activity to the workshop.

Also largely lacking at the workshop was unfortunately the industry perspective. Several companies with a potential or outspoken interest in liquid crystalline soft matter were approached by the organisers prior to the workshop and given the opportunity to contribute in various ways, financially and/or by providing written statements on their views of the field and its future development (speaker slots were not available in the already very full program). Regrettably this work was unsuccessful, some company representatives pointing out that the present difficult financial times limit their interest in and capability of involving in academic research. This is indeed unfortunate because the workshop would have been a good opportunity to coordinate the strong current development of European academic research dealing with liquid crystalline soft matter with strategies of European industry. While much academic research in the field is still at a state where industrial application is hardly considered, there are several researchers who are actually very interested in developing concepts that can be commercially exploited, to the benefits of Europe. A future meeting with strong industry representation may thus also be a very worthwhile follow-up activity, although we presently do not know what would be the appropriate framework for organising such a meeting successfully.

The disappointing disinterest from European industry was well contrasted by the strong interest from the leading international materials science journal *Nature Materials* (incidentally European) who sent their senior editor Dr. Victoria Cleave to attend the full meeting as an observer. This journal, as well as three other international scientific journals (*ChemPhysChem*, *Europhysics News* and *Liquid Crystals Today*), will soon publish reports on the meeting. Perhaps it might be expected that scientific journals can recognise the strategic relevance of developments in a research field at an earlier stage than European companies, many of which are dictated by rather short-term policies. The presence of Dr. Cleave was most beneficial for the meeting, her input during discussions being highly valued by all participants.

An interesting final observation is that, although there were some excellent presentations of results that are interesting to display application of liquid crystals, none of the attendants expressed any interest in organising networks on this topic. Although there are very advanced activities related to displays in (a few) European industries and academic groups the further development at this late stage is strongly industry-focused and not really suitable for academic networks. This confirms the impression that European academic research is more and more leaving display-related liquid crystal research and focusing strongly on other, highly interdisciplinary topics.

Final programme

Note: Dr. Annette Meister had to cancel her attendance with very short notice due to personal reasons. Her presentation does therefore not appear in the final programme.

Tuesday, 26th of May, 2009

Afternoon *Arrival*

20.00-23.00 Get-together buffet on the LC Lab terrace

Wednesday, 27th of May, 2009

09.15-09.40 *Welcome by Convenors*
Jan Lagerwall (Martin-Luther-Universität Halle-Wittenberg, Halle, Germany)
Sven Lagerwall (LC Lab Bandol, Bandol, France)

Session i: Liquid crystals in and from living matter and in medicine
Chair: Ulf Olsson

09.40-10.20 *How to use the bacteriophage system to analyze the structure and phase transitions of DNA in and out of the capsid* (keynote)
Françoise Livolant (Université Paris Sud, Paris, France)

10.20-10.50 *Liquid-Crystallization of Ultrashort DNA and RNA Oligomers: a Phase Behavior Rich in Challenges for Soft-Matter Science*
Tommaso Bellini (Università degli studi di Milano, Milan, Italy)

10.50-11.20 *Coffee / Tea Break*

11.20-11.50 *Unsolved problems in liquid crystal defects and textures, with examples from both synthetic matter and biological systems*
Yves Bouligand (Université Angers & EPHE, Angers, France)

11.50-12.20 *Nanodisks and Nuclisomes - from model membranes to targeted drug delivery*
Katarina Edwards (Uppsala Universitet, Uppsala, Sweden)

12.20-12.50 **Summarizing discussion to session i**

12.50-14.30 *Lunch*

Session ii: Drops, bubbles, tubes, foams and films

Chair: Per Rudquist

14.30-15.10 *Pearl drops* (keynote)

David Quéré

(École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris, Paris, France)

15.10-15.40 *Liquids in one and two dimensions*

Ralf Stannarius (Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany)

15.40-16.10 *Coffee / Tea Break*

16.10-16.40 *Molecule-By-Molecule Nanoassembly in Dynamic Liquid Films*

Owe Orwar (Chalmers University of Technology, Gothenburg, Sweden)

16.40-17.10 *Collective rotations of ferroelectrics on surfaces, stable boolaamphiphile monolayers overcoming collapse, incorporation of large objects into lyotropic LC phases, motion of ions in LCs*

Robert Hołyst (Polskiej akademii nauk, Warsaw, Poland)

17.10-18.10 **EU initiatives discussion**

Thursday, 28th of May, 2009

Session ii (continued)

Chair: Katarina Edwards

09.00-09.30 *Structure Transformations in Surfactant Bilayer Systems*

Ulf Olsson (Lunds universitet, Lund, Sweden)

09.30-10.00 **Summarizing discussion to session ii**

10.00-10.30 *Coffee / Tea Break*

Session iii: Liquid crystal colloids and colloidal liquid crystals

Chair: Claudio Zannoni

10.30-11.10 *Nematic Colloidal Crystals, Superstructures and Optical Microresonators* (keynote)

Igor Muševič (Institut "Jožef Stefan", Ljubljana, Slovenia)

11.10-11.40 *Self-organized nanocomposites: carbon nanotubes ordered by liquid crystals*

Giusy Scalia (ENEA, Portici, Italy)

11.40-12.10 *Single wall carbon nanotubes: liquid crystal properties and nematic ordering in composites*

Christophe Blanc (CNRS-University Montpellier II, Montpellier, France)

12.10-14.00 *Lunch*

14.00-14.30 *Capillary rise of the interface between coexisting isotropic and nematic phases*
Paul van der Schoot (Technische Universiteit Eindhoven, Eindhoven, The Netherlands)

14.30-15.00 *Goethite: extraordinary mineral liquid crystals*
Gert Jan Vroege (Universiteit Utrecht, Utrecht, The Netherlands)

15.00-15.30 **Summarizing discussion to session iii**

15.30-16.00 *Coffee / Tea Break*

Session iv: Liquid crystals for new functional materials, organic electronics and photovoltaics
Chair: Helen Gleeson

16.00-16.40 *Complexity in Liquid Crystal Self Assembly* (keynote)
Carsten Tschierske (Martin-Luther-Universität Halle-Wittenberg, Halle, Germany)

16.40-17.10 *Semiconducting nematic liquid crystals: properties and devices*
Mary O'Neill (University of Hull, Hull, United Kingdom)

17.10-17.30 *Presentation of the European Science Foundation (ESF)*
Kenneth Ruud (Standing Committee for Life, Earth and Environmental Sciences (LESC) / Standing Committee for Physical and Engineering Sciences (PESC))

17.30-18.30 **EU initiatives discussion**

Friday, 29th of May, 2009

Session iv (continued)
Chair: Helen Gleeson

09.00-09.30 *The perspectives of modelling and simulations for device and non-device applications of liquid crystals*
Claudio Zannoni (Università dì Bologna, Bologna, Italy)

09.30-10.00 *Going beyond the reflectance limit of cholesteric liquid crystals: experimental and theoretical investigations*
Michel Mitov
(Centre d'Elaboration de Matériaux et d'Etudes Structurales (CNRS), Toulouse, France)

10.00-10.30 *Electroclinic effect amplification, polydispersity and the stability of smectics*
Frank Gießelmann (University of Stuttgart, Stuttgart, Germany)

10.30-11.00 **Summarizing discussion to session iv**

11.00-11.30 *Coffee / Tea Break*

Session v: Liquid crystals in sensors, actuators and novel optic and electrooptic devices

Chair: Michel Mitov

11.30-12.10 *Switching an (improper) ferro-electric SmC* elastomer* (keynote)
Mark Warner (Cavendish Laboratory, Cambridge University, United Kingdom)

12.10-12.40 *Polymer modified fluid ferroelectrics*
Ingo Dierking (University of Manchester, Manchester, United Kingdom)

12.40-14.30 *Lunch*

14.30-15.00 *A tristable liquid crystal*
Per Rudquist (Chalmers University of Technology, Gothenburg, Sweden)

15.00-15.30 *Electro-optic effects in reduced symmetry liquid crystals*
Helen Gleeson (University of Manchester, Manchester, United Kingdom)

15.30-16.00 **Summarizing discussion to session v**

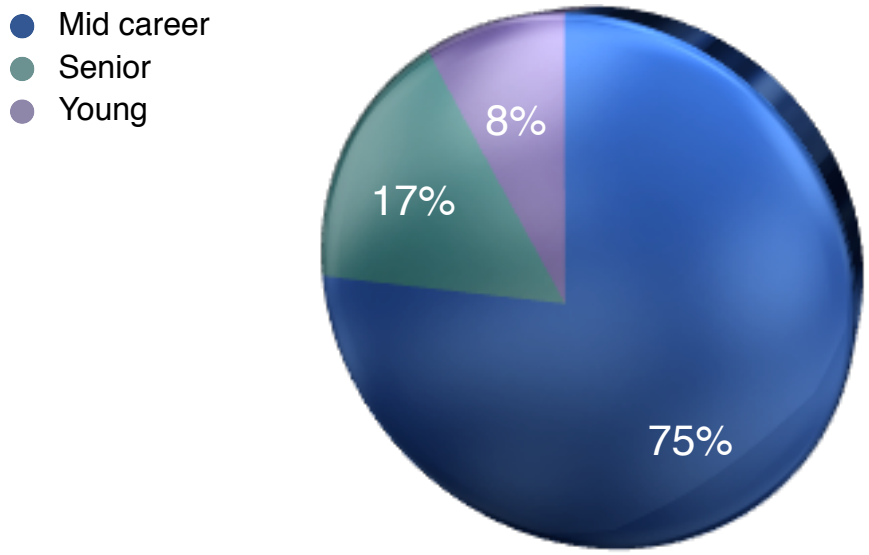
16.00-17.00 **EU initiatives discussion**

17.00-18.30 **Workshop summary & strategic planning**

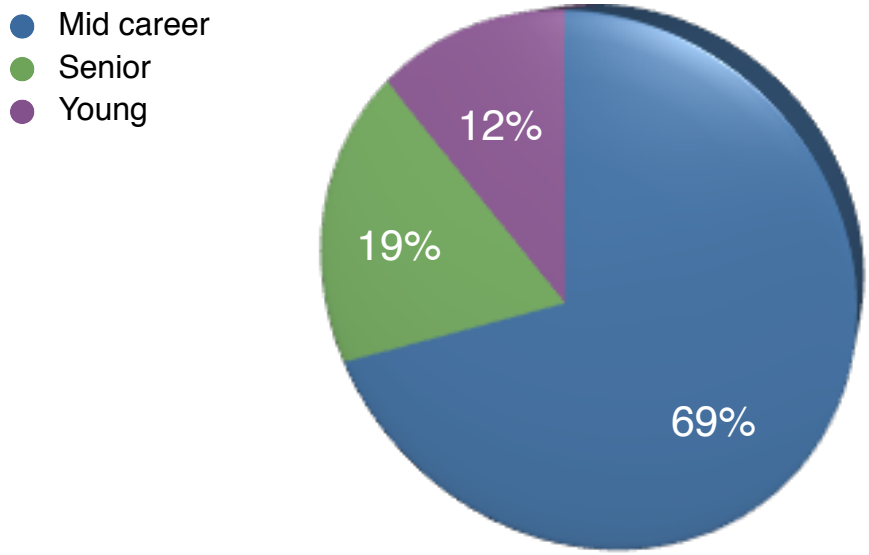
20.00-23.00 Farewell buffet on the LC Lab terrace

Statistical information on participants

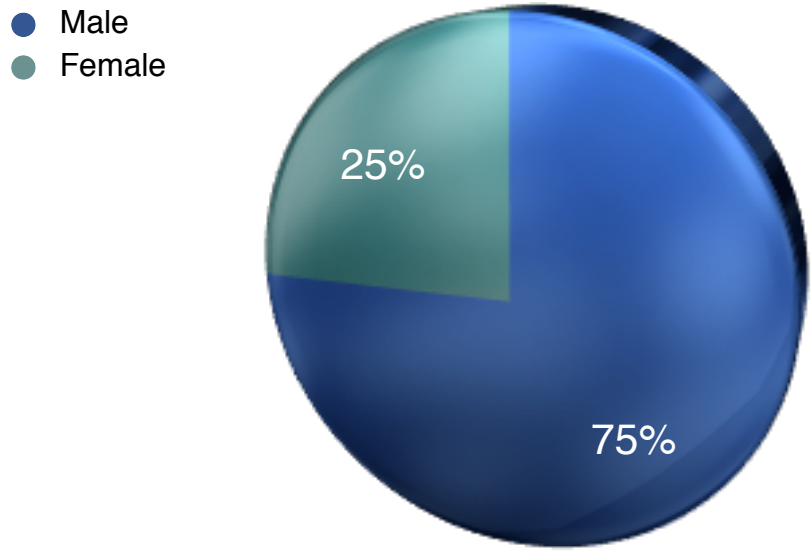
Age structure (invited speakers)



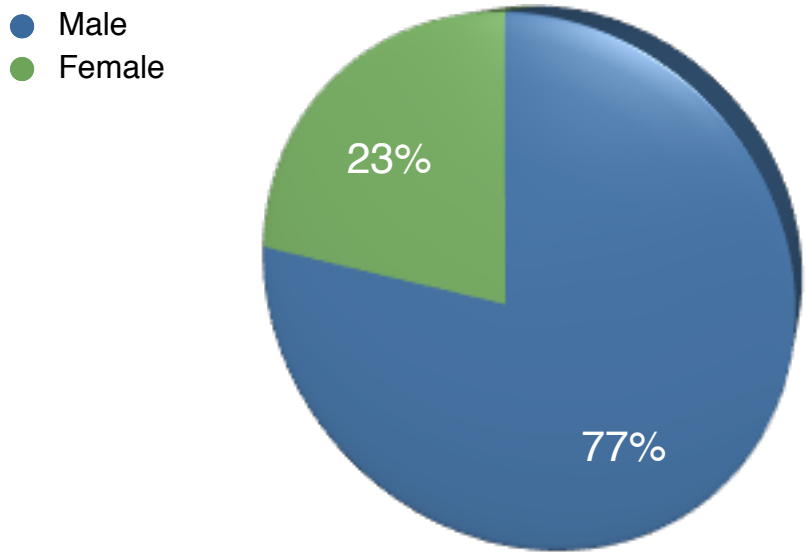
Age structure (speakers and convenors)



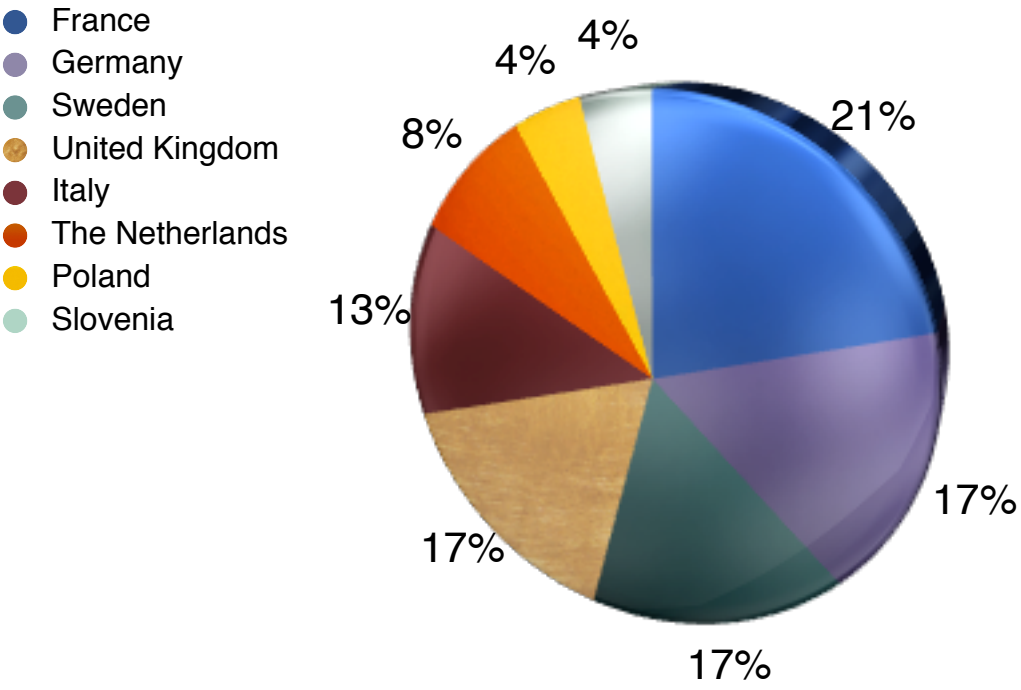
Gender repartition (invited speakers)



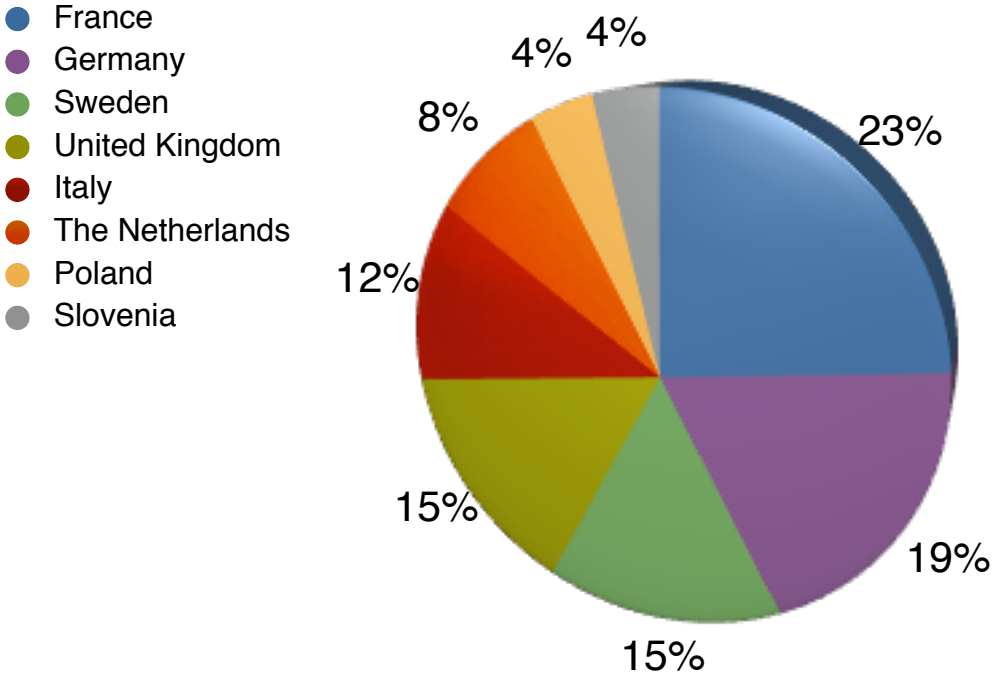
Gender repartition (speakers and convenors)



Country of current affiliation (invited speakers)

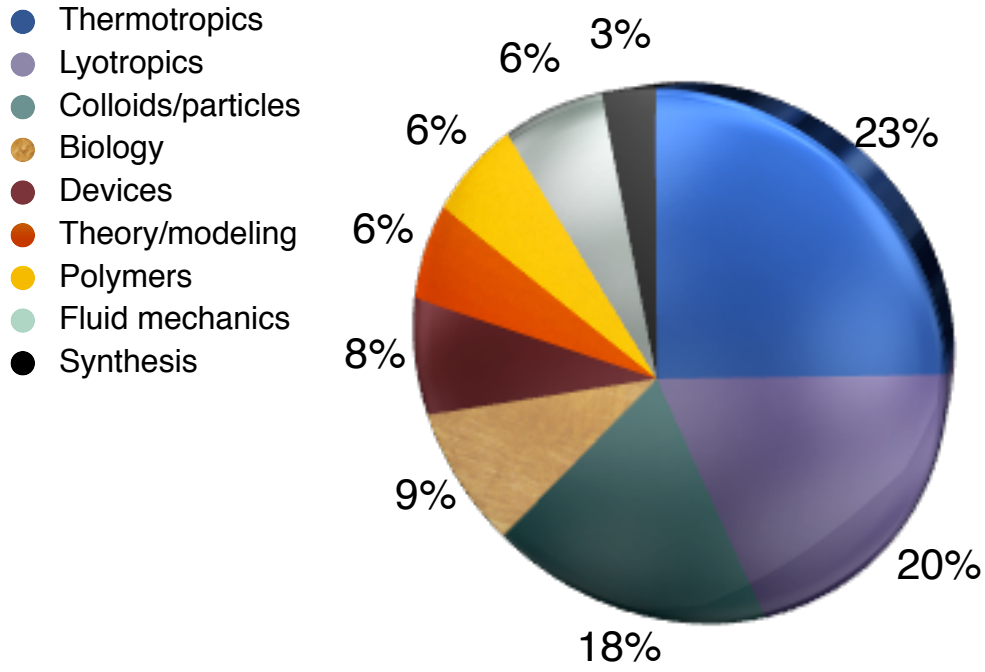


Country of current affiliation (speakers and convenors)



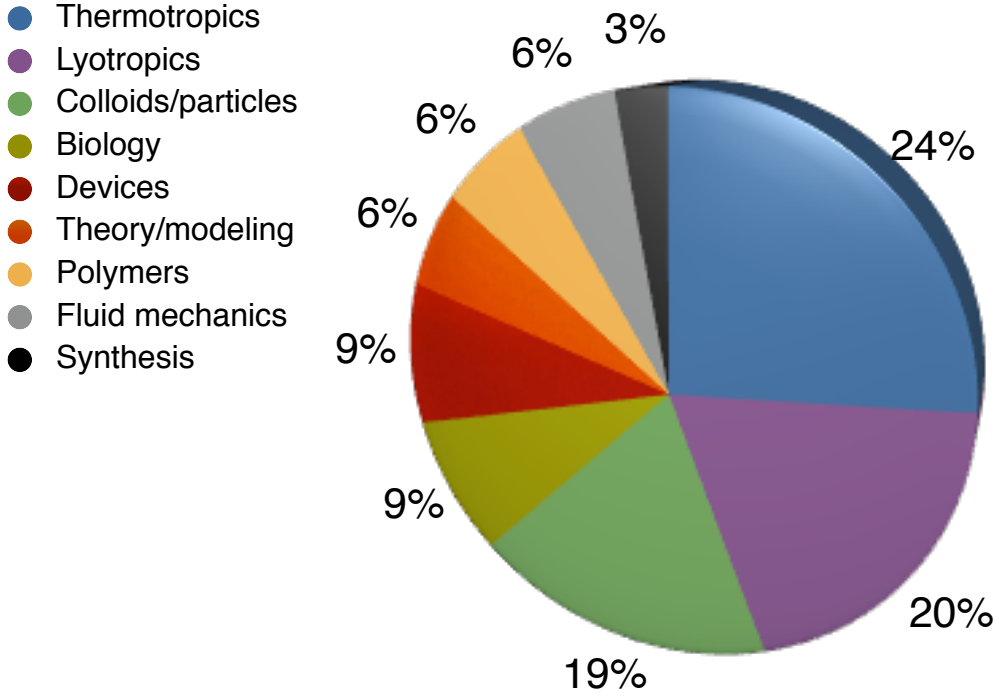
Core expertise (invited speakers)

N.B: one and the same person can contribute to several categories



Core expertise (speakers and convenors)

N.B: one and the same person can contribute to several categories



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