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Igor Muševič

Liquid Crystal Colloids

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Igor Muševič
Jožef Stefan Institute
University of Ljubljana
Ljubljana
Slovenia

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For Maja, Sašo and Nataša

Preface

I started the work on liquid crystal colloids around the year 2000 as a continuation of our experiments on forces between surfaces in liquid crystals. We were using the atomic force microscope (AFM) as a tool to measure structural forces in the nematic and smectic liquid crystals. In those experiments, liquid crystal was confined to a very narrow gap, between 1 and 100 nanometres, typically between a perfectly smooth crystalline surface of mica and the micrometre diameter glass microsphere attached to the cantilever of the AFM. We were looking for the fluctuation forces, also called the Casimir force, of the nematic director field confined to the thin gap between the mica and the microsphere. We never observed the Casimir force, simply because it was to tricky to separate it from the much stronger mean-field forces, which were caused by the gradient of the order parameter in that gap. These mean-field forces between the two surfaces at the nanometre separation were indeed strong, and I was questioning myself whether similar forces between the surfaces of the particles in the nematic liquid crystal exist at a much larger separation, of the order of a micron or so. At the same time, two articles came along my desk: one was the *Science* paper by Poulin, Stark, Lubensky and Wietz, showing beautiful images of the attraction of water droplets in nematics. The other was a paper on photonic crystals by Yablonovitch and Gmitter, published in *Physical Review Letters* in 1989. When reading these papers, I asked myself whether it is possible to build photonic crystals by putting small colloidal particles into nematic liquid crystals, combining the essence the above-mentioned both papers. This was around the year 2000.

At that time, the experiments with colloidal particles in nematics were practically a kind of science fiction, since no tool was available for grabbing individual micrometre diameter particles inside the measuring cell and moving them to an arbitrary position. However, we were lucky that in that period laser tweezers started to emerge as very powerful non-contact tweezers, which use light to trap and manipulate the particles even when they are floating in the nematic liquid crystal sandwiched between two rather thick glass plates.

As mentioned before, we started the experiments with laser tweezers by good luck, using low refractive glass beads, putting them in the nematic liquid crystal and trying to see whether the tweezers are able to grab such a particle and move it. It came as a big surprise to the three of us, Miha Škarabot, Igor Poberaj and myself, when we saw that glass beads could nicely be trapped in the nematic liquid crystal, although the refractive index of glass is lower than the refractive indices of both nematic liquid crystal used in the experiments. I explained this anomalous trapping by noting that polarisation of the laser tweezers is an important parameter and that the second important phenomenon is the action of the strong electric field of the laser tweezers on the nematic liquid crystal itself. We could soon explain this anomalous trapping on a general grounds by considering elastic deformation of nematic liquid crystal by light and the polarisation of light, which selectively grabs the nematic director along the direction of larger polarizibility and moves the particle together with the field.

After the work on this anomalous trapping of colloids by optical tweezers was published, there was a lot of excitement and new ideas on what physics experiments could be done with the laser tweezers. This result opened the exciting pathway to the assembly of the first 2D nematic colloidal crystal in 2006. Another milestone occurred in the same year 2006, when Miha Ravnik proposed to use local quench of the nematic liquid crystal colloids from the isotropic phase to the nematic phase and entangle two colloidal particles. This was soon realised in the experiment by using the absorption of the laser tweezers in the nematic liquid crystal colloids to melt the nematic and then quench it. The result was colloidal entanglement, where colloidal particles could be entangled by topological defect loops. The entanglement later provided the most complex colloidal binding in the nematic liquid crystals, i.e. knotting and linking of colloids, which was observed by Uroš Tkalec and myself in 2010. Linking and knotting of the nematic liquid crystal opened the doors to the experimental topology in liquid crystals and what followed were several years of very creative and exciting exploration of this complex phenomenon by many different groups all over the world.

Along the work on nematic colloids, I began in 2007 with Matjaž Humar a parallel work on an entirely new line of research with the aim of using the nematic dispersions for microphotonics. There was only a slight hint at that time that liquid crystals could provide a beautiful setting for the realisation of tiny photonic elements, such as optical microcavities, microlasers and photonic microfibers. Indeed, all this was found latter in the dispersions of nematic or cholesteric liquid crystals in other immiscible fluids, such as water. This led me to consider whether one could use the structural forces for binding and entangling colloidal particles in the nematics together with the photonic properties of nematic dispersions. The aim is to create a soft matter analogue to the solid state microphotonic circuits, where instead of silicon, a soft matter is used to self-assemble into a topological photonic soft matter. At present, we have clear proof that such technology based on soft matter self-assembly is indeed possible.

This work is written as a kind of retrospective of all the mentioned studies and it follows, more or less chronologically, the experimental work performed in the last decade, starting from the year 2004. It turns out that telling the story in a chronological order is the best way to present the development of ideas from simple beginnings to very complex issues. Most of the work in this book was performed in my laboratory at the J. Stefan Institute; however, the book would be far from complete without including the work of other researchers from very different laboratories around the world. I did my best to include all relevant work in this field and I hope that I have not missed any important references.

Ljubljana, Slovenia Igor Muševič
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Igor Muševič

Contents