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Editorial

State-of-the-Art Liquid Crystals Research in UK

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A number of countries could reasonably produce a collection represented a name such as "State-of-the-Art Research in Liquid Crystals". The history of liquid crystal research [1–3] dates back to approximately 135 years ago in the German speaking countries, when Friedrich Reinitzer (Figure 1), a botanist from Austria, discovered the two supposed melting points of cholesteryl benzoate [4] at the German University in Prague. In his article, he clearly described the liquid crystalline behaviour of this compound, including the phenomenon of selective reflection, but he was unable to precisely explain the observed behaviour. This explanation was provided within a year's time by the German physicist Otto Lehmann (Figure 1), who was the successor of Heinrich Hertz at the University of Karlsruhe. Lehmann first coined the phrase "liquid crystal" [5] and spent the rest of his life in research attempting to foster the acceptance of his concepts by much of the physical chemistry community in Germany, with his greatest opponent being Gustav Tammann. Today, of course, we know that Otto Lehmann's view of the liquid crystal state is correct. This leads us to mention Daniel Vorländer (Figure 1), a synthetic chemist at the University of Halle, who remains among the top ten most productive listed liquid crystal organic chemists as the field expands through new research on new phases of matter [6]. Also well-known in the field of physical chemistry is the name Rudolf Schenk (Figure 1), who studied chemistry in Halle and later moved to the University of Marburg, where he investigated liquid crystals [7], producing results in favour of Lehmann's views rather than those of Tammann.

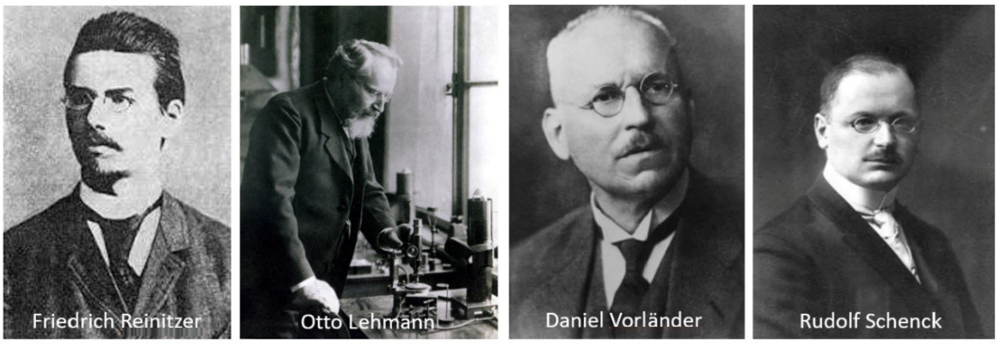

Figure 1. The German liquid crystal researchers of the early days: Friedrich Reinitzer, Otto Lehmann, Daniel Vorländer, and Rudolf Schenk.

At the same time, interest in liquid crystals was also growing in France, where Charles-Victor Maugin (Figure 2) explored the polarisation properties of twisted liquid crystals and cholesteric phases [8] and the effects of magnetic fields [9]. Francois Grandjean (Figure 2) was the first to describe the importance of surface interactions for the orientation of liquid crystals [10] and developed a method for measuring the cholesteric pitch in wedge cells. It was finally Georges Friedel (Figure 2) who, in 1922, categorised the then-discovered liquid crystals according to their structural properties in the first detailed and extensive review of the subject [11]. He proposed three mesomorphic states, including the *nematic*, *cholesteric*,

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and *smectic*. Grandjean had already described the layered structure of smectics based on his observation of the steps of uncovered droplets on a clean plane glass substrate [10]. Today, of course, we know that this classification is not remotely detailed enough to account for all the different liquid crystal phases, nor does it truly make much sense as a method used to distinguish between the nematic and cholesteric states, as the latter is only the chiral version of the former, albeit with a greatly different spontaneous structure and properties.

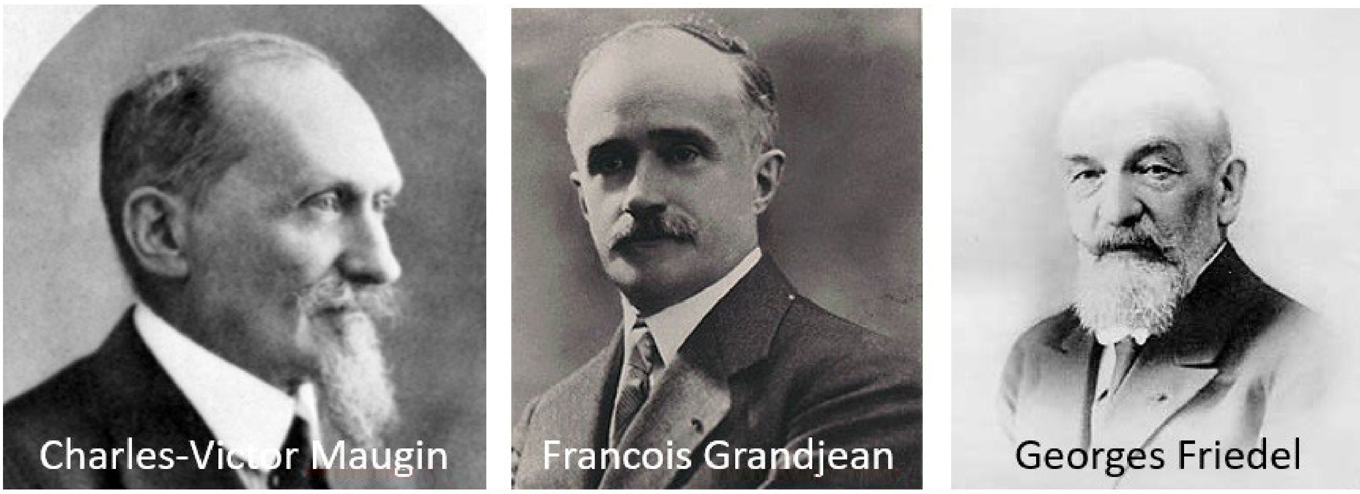

Figure 2. The French liquid crystal researchers of the early days: Charles Maugin, Francois Grandjean, and Georges Friedel.

Smectic polymorphism and the layered structure of the smectic phase also constituted the focus of one of the famous early meetings and, quite possibly, the first international conference on liquid crystals, the Faraday Discussion Meeting of the Royal Society, held in 1933. The contributions and discussions are documented in the *Transactions of the Faraday Society* 1933, vol 29, issue 140 (https://ur.booksc.me/journal/24896/29/140, last accessed on 14 September 2022).

Following the birth of liquid crystal research and the establishment of this fourth state of matter, research efforts became more international in nature. Arguably, one of the pioneering figures in the field was the Russian physicist Vsevolod Konstantinovich Frederiks (Figure 3), who was the first to describe the magnetic [12] and, later, the electric reorientation of the director by externally applied fields, now known as the Frederiks transition, the basis of most of the display devices that have enabled the significant progression in liquid crystal research since the 1970s. In this category, we must also mention the Swedish scientist Carl Wilhelm Oseen (Figure 3), who was the first to formulate a description of the elastic properties of nematics [13], and Marian Miesowicz (Figure 3) from the Mining Academy in Cracow, Poland, who studied the viscosities of liquid crystals under magnetic fields [14] and later introduced the three viscosity coefficients that now bear his name [15]. Equally worthy of note are Hans Ernst Werner Zocher (Figure 3), a German born researcher who worked at the University of Prague and later emigrated to Brazil, who is known for his work on vanadium pentoxide lyotropic liquid crystals [16] but more so for his theoretical contributions regarding field effects on nematic liquid crystals [17]. The Russian scholar Victor Nikolaevich Tsvetkov (Figure 3) introduced the orientational order parameter [18], whose temperature dependence was predicted in the classic publications of Wilhelm Maier and Alfred Saupe (Figure 3) [19,20], thus producing the first working theory of the nematic liquid crystalline phase. It took more than 70 years from the time of the discovery of liquid crystals to their first functional description. This basic field description was later supplemented by the Landau-type description of the isotropic to nematic transition of Pierre-Gilles de Gennes (Figure 3) [21], who was awarded with the Nobel Prize for Physics in 1991 for his work on liquid crystals and polymers. His book on *The Physics of Liquid Crystals* [22] is still considered as a kind of bible for researchers in this field.

Figure 3. Pioneering international liquid crystal scientists before the display era: Fredericks (Russia), Oseen (Sweden), Miesowicz (Poland), Zocher (Germany, Brazil), Tsvetkov (Russia), Maier and Saupe (Germany), and de Gennes (France).

By this point, the time was ripe for researchers to not only engage in fundamental research on liquid crystals and the synthesis of novel, increasingly complicated mesogens but also to think critically about the applications and structure–property relationships that enable this synthesis. This was also the time when liquid crystal research truly blossomed in the UK. Frederick Charles Frank (Figure 4) did not published a great deal on the topic of liquid crystals, yet his influence was far-reaching, as he revised the theory of elasticity formulated by Oseen to produce the form in which it is known today [23], with the three bulk elastic constants describing splay, twist, and bend deformations. Frank's description also opened the door to the experimental determination of these functionally vital constants.

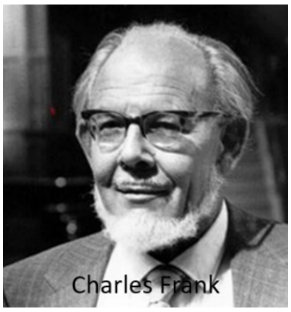

Figure 4. Sir Charles Frank had a lasting impact on British liquid crystal research, despite having not published many papers on the topic himself.

Having been introduced to liquid crystals by Brynmor Jones, George Gray, Head of Department at Hull University, published his first paper in the field in 1951, entitled "Mesomorphism of some alkoxynaphthoic acids" [24]. During the 1960s, George William Gray (Figure 5) was working as a synthetic chemist at the University of Hull with the aim of producing liquid crystals at room temperature, the ultimate prerequisite for any display device. Being aware of the structure–property relationships of liquid crystals, which were also established during this time by the Halle group in Germany, Gray succeeded in his task, and the family of the cyano-biphenyls that are still employed today was born, comprising single-component liquid crystals with room temperature nematic and smectic phases [25]. The melting and clearing temperatures could still be improved using mixtures with similar rod-like mesogens, and materials which possessed a reasonable nematic temperature range for the operation of displays were obtained. Ben Sturgeon (Figure 5), a senior scientist at BDH (later part of Merck) was instrumental in scaling-up the production of the liquid crystalline cyano-biphenyls, thus enabling the worldwide development of the display industry that is now a global multi-billion dollar business. This would not have been possible without the achievements of George Gray, the risks taken by Ben Sturgeon, and the engineering skills of Cyril Hilsum (Figure 5), an engineer who pioneered the development of modern display technology, and his political persuasion of the Ministry of Defence.

Figure 5. UK liquid crystal scientists who were instrumental in the development of the LCD technology: George Gray, Ben Sturgeon, and Cyril Hilsum.

The displays of Heilmeier and Zanoni (Figure 6) [26] or Schadt and Helfrich (Figure 6) [27] could only function and attain market-competitive value with room-temperature materials such as 5CB (or K15, as it was known in those days).

Figure 6. The pioneers of the invention of liquid crystal displays: Heilmeier and Zanoni (dynamic scattering display), as well as Schadt and Helfrich (twisted nematic display).

After the development of room-temperature materials and the invention of the first displays, naturally, both fundamental and applied liquid crystal research continued in the UK. The mathematical physicist Frank Matthews Leslie (Figure 7) (University of Strathclyde), together with Jerald Ericksen, who is mostly known for his development of a continuous theory of the mechanical behaviour of nematics [28], introduced the viscosity parameters known as Leslie coefficients. Geoffrey Luckhurst (Figure 7), a chemical physicist at the University of Southampton, has made seminal contributions to the field with respect to the synthesis and NMR and ESR characterisation of materials, as well as computer simulations and theory. Peter Raynes (Figure 7), an optoelectronics engineer at Oxford University, has long been involved in research on display design and characterisation. Together with Hulme and Harrison, he invented a method for formulating mixtures of cyano-biphenyls, which was used by Ben Sturgeon at BDH in the commercialization of liquid crystal mixtures, such as E7, first used in LCDs. Raynes has also contributed significantly to our understanding of the electro-optics of liquid crystals. During his time at the Royal Signals and Radar Establishment (RSRE), he invented the super-twisted nematic (STN) display (with Colin Waters), which can be found in most of the early alpha-numeric flat-panel screens. Similarly, Roy Sambles (Figure 7) is an experimental physicist who worked at the University of Exeter, where he studied the interaction between light and matter, with a special emphasis on surface plasmons and microwave photonics. Of course, one cannot fail to mention John Goodby (Figure 7), who worked at the University of Hull and, later, the University of York. His contributions to research on the synthesis of liquid crystal materials in the fields of ferroelectric liquid crystals, low birefringent materials, and chiral liquid crystals, in general, were truly seminal. He later broadened his interests to encompass self-organising materials and complex fluids, and through his work, he brought partially ordered fluids into the realm of materials chemistry and functional materials. The late Mark Warner (Figure 7) from the University of Cambridge was a theoretical physicist, who was one of the founders of the field of liquid crystalline elastomers and actuators.

Figure 7. The next generation of UK liquid crystal researchers who made seminal and pioneering contributions to the field: Frank Leslie, Geoffrey Luckhurst, Peter Raynes, Roy Sambles, John Goodby, and Mark Warner.

In this Special Issue of the journal *Crystals*, "State-of-the-Art Liquid Crystal Research in the UK", we have collected a range of articles and reviews that reflect on this previous work and provide an overview of the variety and diversity of current liquid crystal research in the UK. It includes papers on the history of liquid crystal contributions in the UK, experimental physics and chemistry, simulations, and novel applications. The publications were mainly produced by active members of the research community, including researchers from the universities of Leeds, Aberdeen, Manchester, Durham, Oxford, and York. This range of contributions demonstrates the breadth of liquid crystal research and provides a useful cross-section of the work in progress in the UK today.

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