

CRYSTALS THAT FLOW

THE LIQUID CRYSTALS BOOK SERIES

Edited by

G.W. GRAY, J.W. GOODBY & A. FUKUDA

The Liquid Crystals book series publishes authoritative accounts of all aspects of the field, ranging from the basic fundamentals to the forefront of research; from the physics of liquid crystals to their chemical and biological properties; and, from their self-assembling structures to their applications in devices. The series will provide readers new to liquid crystals with a firm grounding in the subject, while experienced scientists and liquid crystallographers will find that the series is an indispensable resource.

CRYSTALS THAT FLOW

**Classic papers from the history of liquid
crystals**

Compiled with translation and commentary by

*Timothy J. Sluckin, David A. Dunmur
and Horst Stegemeyer*



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CONTENTS

<i>Preface</i>	xii
<i>Acknowledgments</i>	xviii
Section A	
The early period: liquid crystals or anisotropic liquids?	1
Introduction	3
A1. F. Reinitzer Contributions to the understanding of cholesterol (Beiträge zur Kenntiss des Cholesterins) <i>Monatshefte für Chemie (Wien)</i> 9 , 421–41 (1888) (transl.)	26
A2. O. Lehmann On flowing crystals (Über fließende Krystalle) <i>Zeitschrift für Physikalische Chemie</i> 4 , 462–72 (1889) (transl.)	42
A3. L. Gattermann and A. Ritschke On azoxyphenol ethers (Ueber Azoxyphenetoläther) <i>Berichte der Deutschen Chemischen Gesellschaft</i> 23 , 1738–50 (1890) (transl.)	54
A4. R. Schenck On crystalline liquids and liquid crystals (Über die Natur der kristallinen Flüssigkeiten und der flüssigen Krystalle) <i>Zeitschrift für Elektrochemie</i> 11 , 951–55 (1905) (transl.)	64

CONTENTS

- A5. D. Vorländer
 On crystalline-liquid substances
 (Über krystallinisch-flüssige Substanzen)
Berichte der Deutschen Chemischen Gesellschaft **39**,
 803–10 (1906) (*transl.*) 76
- A6. D. Vorländer
 Influence of molecular configuration on the
 crystalline-liquid state
 (Einfluß der molekularen Gestalt auf den
 krystallinisch-flüssigen Zustand)
Berichte der Deutschen Chemischen Gesellschaft **40**,
 1970–72 (1907) (*transl.*) 84
- A7. E. Bose
 On the theory of the anisotropic liquids
 (Zur Theorie der anisotropen Flüssigkeiten)
Physikalische Zeitschrift **9**, 708–13 (1908) (*transl.*) 90
- A8. Ch. Mauguin
 On the liquid crystals of Lehmann
 (Sur les cristaux liquides de Lehmann)
Bulletin de la Société française de Minéralogie **34**,
 71–117 (1911) (*transl. extracts*) 100
- A9. Ch. Mauguin
 Orientation of liquid crystals by a magnetic field
 (Orientation des cristaux liquides par le champ
 magnétique)
Comptes rendus de l'Académie des Sciences **152**,
 1680–83 (1911) (*transl.*) 122
- A10. F. Grandjean
 The orientation of anisotropic liquids on crystals
 (Orientation des liquides anisotropes sur les
 cristaux)
Bulletin de la Société française de Minéralogie **39**,
 164–213 (1916) (*transl. extracts*) 128

Section B	
The inter-war period: anisotropic liquids or mesomorphic phases?	137
Introduction	139
B1. G. Friedel The mesomorphic states of matter (Les états mésomorphes de la matière) <i>Annales de Physique</i> 18 , 273–474 (1922) (transl. extracts)	162
B2. M. de Broglie and E. Friedel Diffraction of X-rays by smectic substances (La diffraction des Rayons X par les corps smectiques) <i>Comptes rendus de l'Académie des Sciences</i> 176 , 738–40 (1923) (transl.)	212
B3. V. Fréedericksz and V. Zolina On the use of a magnetic field in the measurement of the forces tending to orient an anisotropic liquid in a thin homogeneous layer <i>Transactions of the American Electrochemical Society</i> 55 , 85–96 (1929)	219
B4. P.P. Ewald <i>et al.</i> Translated extracts from General Discussion on liquid crystals <i>Zeitschrift für Kristallographie</i> 79 , 269–347 (1931)	236
B5. C.W. Oseen The theory of liquid crystals <i>Transactions of the Faraday Society</i> 29 , 883–900 (1933)	255
B6. L.S. Ornstein and W. Kast New arguments for the swarm theory of liquid crystals <i>Transactions of the Faraday Society</i> 29 , 930–44 (1933)	273
B7. H. Zocher The effect of a magnetic field on the nematic state <i>Transactions of the Faraday Society</i> 29 , 945–57 (1933)	289
B8. J.D. Bernal <i>et al.</i> Extracts from General Discussion on liquid crystals <i>Transactions of the Faraday Society</i> 29 , 1060–85 (1933)	303

CONTENTS

B9. M. Mięsowicz Influence of a magnetic field on the viscosity of para-azoxyanisole <i>Nature</i> 136 , 261 (1936)	315
B10. M. Mięsowicz The three coefficients of viscosity of anisotropic liquids <i>Nature</i> 158 , 27 (1946)	317
B11. P. Chatelain On the orientation of liquid crystals by rubbed surfaces: experimental study (Sur l'orientation des cristaux liquides par les surfaces frottées) <i>Comptes rendus de l'Académie des Sciences</i> 213 , 875–76 (1941) (transl.)	320
B12. P. Chatelain On the orientation of liquid crystals by rubbed surfaces (Sur l'orientation des cristaux liquides par les surfaces frottées) <i>Bulletin de la Société française de Minéralogie</i> 66 , 105–30 (1944) (transl. extracts)	324
Section C	
The modern physical picture	333
Introduction	335
C1. F. Grandjean On the application of the theory of magnetism to anisotropic fluids (Sur l'application de la théorie du magnétisme aux liquides anisotropes) <i>Comptes rendus de l'Académie des Sciences</i> 164 , 280–83 (1917) (transl.)	364
C2. V.N. Tsvetkov On molecular order in the anisotropic liquid phase (Über die Molekülanordnung in der anisotrop-flüssigen Phase) <i>Acta Physicochimica U.R.S.S.</i> 15 , 132–47 (1942) (transl.)	368

CONTENTS

C3.	W. Maier and A. Saupe A simple molecular theory of the nematic liquid-crystalline state (Eine einfache molekulare Theorie des nematischen kristallinflüssigen Zustandes) <i>Zeitschrift Naturforschung</i> 13a , 564–66 (1958) (transl.)	380
C4.	F.C. Frank On the theory of liquid crystals <i>Discussions of the Faraday Society</i> 25 , 19–28 (1958)	389
C5.	H. Arnold and H. Sackmann Isomorphic relationships between crystalline-liquid phases. Part 4: Miscibility in binary systems with several smectic phases (Isomorphiebeziehungen zwischen kristallin-flüssigen Phasen. 4. Mitteilung: Mischbarkeit in binären Systemen mit mehreren smektischen Phasen) <i>Zeitschrift für Elektrochemie</i> 11 , 1171–77 (1959) (transl.)	400
C6.	F.M. Leslie Some constitutive equations for liquid crystals <i>Archives for Rational Mechanics and Analysis</i> 28 , 265–83 (1968)	417
C7.	P.G. de Gennes Short-range order effects in the isotropic phase of nematics and cholesterics <i>Molecular Crystals and Liquid Crystals</i> 12 , 193–214 (1971)	437
Section D		
The development of liquid crystal display technology		461
	Introduction	463
D1.	B. Levin and N. Levin (Marconi's Wireless Telegraph Company) Improvements in or relating to Light Valves <i>British Patent</i> 441, 274 (1936)	487
D2.	R. Williams Domains in liquid crystals <i>Journal of Chemical Physics</i> 39 , 384–88 (1963)	497
D3.	G.H. Heilmeyer, L.A. Zanoni and L.A. Barton Dynamic scattering: a new electrooptic effect in certain classes of nematic liquid crystals <i>Proc. I.E.E.E.</i> 56 , 1162–71 (1968)	503

CONTENTS

D4. H. Kelker and B. Scheurle A liquid-crystalline (nematic) phase with a particularly low solidification point <i>Angewandte Chemie, International Edition</i> 8 , 884–85 (1969)	515
D5. F.M. Leslie Distortion of twisted orientation patterns in liquid crystals by magnetic fields <i>Molecular Crystals and Liquid Crystals</i> 12 , 57–72 (1970)	519
D6. M. Schadt and W. Helfrich Voltage-dependent optical activity of a twisted nematic liquid crystal <i>Applied Physics Letters</i> 18 , 127–28 (1971)	537
D7. G.W. Gray, K.J. Harrison and J.A. Nash New family of nematic liquid crystals for displays <i>Electronics Letters</i> 9 , 130–31 (1973)	543
D8. R.B. Meyer, L. Liébert, L. Strzelecki and P. Keller Ferroelectric liquid crystals <i>Journal de Physique</i> 26 , L69–71 (1975)	549
D9. N.A. Clark and S.T. Lagerwall Submicrosecond bistable electro-optic switching in liquid crystals <i>Applied Physics Letters</i> 36 , 899–901 (1980)	553
Section E Lyotropic and polymeric liquid crystals	559
Introduction	561
E1. R. Zsigmondy and W. Bachmann On gels: Ultramicroscopic studies on soap solutions and soap gels (Über Gallerten. Ultramikroskopische Studien an Seifenlösungen und gallerten) <i>Kolloid-Zeitschrift</i> 11 , 145–57 (1912) (<i>transl. extracts</i>)	588
E2. F.C. Bawden, N.W. Pirie, J.D. Bernal and I. Fankuchen Liquid crystalline substances from virus-infected plants <i>Nature</i> 138 , 1051–52 (1936)	601

CONTENTS

E3.	J. Stauff On micellar types of aqueous soap solutions (Die Mizellarten wässriger Seifenlösungen) <i>Kolloid-Zeitschrift</i> 89 , 224–33 (1939) (transl.)	608
E4.	L. Onsager The effects of shape on the interaction of colloidal particles <i>Annals of the New York Academy of Sciences</i> 51 , 627–59 (1949)	625
E5.	P.J. Flory Phase equilibria in solutions of rod-like particles <i>Proceedings of the Royal Society of London A</i> 234 , 73–89 (1956)	659
E6.	V. Luzzati, H. Mustacchi, A. Skoulios and F. Husson The structure of association colloids I. The liquid-crystalline phases of amphiphile-water systems (La structure des colloïdes d'association. I. Les phases liquide-crystallines des systèmes amphiphile-eau) <i>Acta Crystallographica</i> 13 , 660–67 (1960) (transl.)	676
E7.	A. Roviello and A. Sirigu Mesophasic structures in polymers. A preliminary account on the mesophases of some poly-alkanoates of <i>p,p'</i> -di-hydroxy- α,α' -di-methyl benzalazine <i>Journal of Polymer Science B: Polymer Letters</i> <i>Edition</i> 13 , 455–63 (1975)	697
E8.	H. Finkelmann, H. Ringsdorf and J.H. Wendorff Model considerations and examples of enantiotropic liquid crystalline polymers <i>Makromolekulare Chemie</i> 179 , 273–76 (1978)	707
	<i>Index of biographies</i>	713
	<i>Author index</i>	715
	<i>Subject index</i>	723

PREFACE

Science, unlike many other human activities, progresses through the published word, so in some sense the history of science is simply the published scientific literature. Nevertheless, amongst the vast accumulation of papers, many do not really contribute to scientific progress and some are just plain wrong. There are, however, occasional gems of inspiration, serendipitous discoveries of important new phenomena and more rarely landmarks of understanding. These might reasonably be called “classic papers”, and a collection of them focussed on a particular theme provides some sort of history of an aspect of science. This volume of classic papers attempts to tell the story of the development of liquid crystal science through the words of the scientists themselves, as reported in their original publications. But the recorded history of a scientific idea often hides important pointers towards a deeper understanding, not only of the underlying science, but also of its interaction with the greater world outside. Thus the reprinted papers are augmented with a series of essays, which place the papers in context, and give some flavour of the scientific milieu of the period during which they were published.

The science of liquid crystals began more than a century ago with a baffling observation of two melting points in a single pure substance by a German botanist (Friedrich Reinitzer). The botanist passed his results to a physicist (Otto Lehmann), who realised that he was studying something interesting, but misidentified the physical phenomenon as crystalline in origin. Despite his misidentification, Lehmann gave us a name that stuck: **liquid crystals**, and our subject was born. Later a combative French crystallographer (Georges Friedel) realised that the materials were not crystals at all, but special liquids, albeit exhibiting some properties akin to those of crystals, and put the subject on a firmer footing. The early story of liquid crystals involves botanists, chemists, physicists, mineralogists and mathematicians mainly from Europe, who pursued their interests through a turbulent period of history involving wars (the Great War and the Second World War) and revolutions (the birth of communism). The events of history took their toll on our scientists (Vsevolod Konstantinovich Frederiks published and perished in one of Stalin’s gulags), but did nothing to stem their fervour or

determination to promote their ideas. After the Second World War, in common with many other physical sciences, liquid crystals benefited from a burgeoning in both fundamental science and applications. The former resulted in a Nobel Prize for one of the scientists featured in our collection (Pierre-Gilles de Gennes), while the latter led to the birth of a multi-billion dollar display industry, and fame and fortune for other players in the story of liquid crystals. This scientific odyssey is mapped by the classic papers we have selected, but we intend that our essays of introduction and the biographies of the principal authors will reinforce the human perspective of the story. Despite the historical content of this book, we cannot claim to have produced a definitive history of liquid crystal science. We have had access to some original documents, including of course the selected papers, but there is a wealth of information still to be assessed. We are optimistically confident that further study will not change the conclusions we have reached, but there are still many interesting stories to be told in the history of liquid crystals.

This book is divided into five separate sections, each headed by an essay of introduction. The papers of the first three sections and their commentaries are arranged chronologically, and these record important experiments and theoretical developments concerning the thermotropic liquid crystals discovered by Reinitzer. These papers take us from the early scientific arguments about the existence of liquid crystals to an increasingly sophisticated interpretation of their properties, and an enormous increase in the number of materials and phases available for study. This formative period for liquid crystals ends, in the context of this volume, around 1970. Such an early cut-off should not be seen to diminish the importance of subsequent studies, but these are more appropriate for scholarly scientific review than for this history. This volume is not the first to attempt a history of liquid crystals, and we refer the interested reader to the publications listed at the end of this Preface.

Our fourth section takes a different time-slice through the subject of liquid crystals, and its focus is the development of the liquid crystal display, which is now familiar to all. This part of our story ends rather arbitrarily around 1980, and so neglects many more recent important contributions, which have transformed liquid crystal displays from novelties to high-value, high-quality mass-produced electronic goods. In particular, the imaginative technical developments in displays that have come from Japanese scientists have largely taken place since 1980. The fifth and final section deals with lyotropic and polymeric liquid crystals, the origins of which are sufficiently different from thermotropic liquid crystals to justify a separate treatment. Indeed, lyotropic liquid crystals, so-named because their liquid crystallinity involves principally a reduction in water content of a solution rather than a reduction in temperature, have their origins in the soaps of the ancients. Furthermore, polymer liquid crystals in biology were recorded in the scientific literature, even before Reinitzer's studies, but have taken much longer to understand. This part of our story takes us back to the early part of the twentieth century, and Nobel-prize winner Richard Zsigmondy, and his studies of gel

phases. Since that time, the understanding of lyotropics progressed largely in parallel with that of thermotropic liquid crystals, with occasional points of contact. Theoretical developments also emerged from different sources, with important contributions from other Nobel prize winners, Paul Flory and Lars Onsager. We finish this part of the story in the early 1980s, with the emergence of polymer liquid crystals and their applications. With hindsight, we can now see that the stories of lyotropic, polymer and thermotropic liquid crystals are all part of the same scientific picture, but history saw otherwise.

From the hundreds of papers that might be regarded as ‘classic’, we have been forced to make a selection. Some of the papers included (for example, those of Lehmann, Reinitzer and Georges Friedel) would appear in any compilation. In the case of others, the choice is not so obvious. Those who know this literature well will have their own favourites, and some of these may not be the same as ours. The science of liquid crystals crosses disciplinary boundaries, and to reflect this, we have tried to choose representative papers from the major strands contributing to the current state of liquid crystal knowledge.

Much of the early work on liquid crystals is published in German or French (and occasionally in Russian), and in order to make this accessible to a readership around the world, we have translated a number of the selected papers into English. We apologise to French and German readers in particular for this necessity, for taken as literature, the original is surely better than a translation. Apart from the papers by Reinitzer and Saupe, new translations have been made by the present authors for this volume. We hope that the translated papers give a faithful representation of not only the meaning but also the spirit of the originals. Inevitably readers will find minor errors: for these we apologise.

Two authors require particular mention. To remark that the writing style of Otto Lehmann was ponderous would be to indulge in weighty understatement. We found the translation of Lehmann almost impossible, for his sentences were longer than some people’s books! Nevertheless the task is worth the effort, for the content is remarkable, both from a historical and from a scientific viewpoint. Georges Friedel, although eleven years younger than Lehmann, was his scientific colleague and rival. His 1922 paper was a classic which leaves a mark on the science of liquid crystals to this day.

The genesis of this volume lies in an inaugural lecture given by one of the present authors (TJS) in March 2000, celebrating his election to the Chair of Applied Mathematical Physics at the University of Southampton. The title of this lecture “Fluids with attitude – the story of liquid crystals from oddity to technology” was an attempt to review of the origins of the science of liquid crystals for a general university audience, and to show how a multi-billion dollar industry developed from Reinitzer’s esoteric observations on the biochemistry of carrots. The original hope was that the lecture could be made available to a wider audience through publication. The single lecture has matured into the present volume of more than seven hundred pages. To do proper justice to the subject of liquid

crystals, which embraces many aspects of science including chemistry, physics, mathematics, biology, materials science, and electronic engineering, has required the involvement of two other authors (DAD and HS).

A volume such as this has required input from many sources. Many colleagues have provided advice and guidance concerning both the choice of papers, and their significance. Peter Knoll was kind enough to provide copies of the unpublished monographs he co-authored with Hans Kelker on the early history of liquid crystals. Peter Raynes and Cyril Hilsum suffered the indignity of formal interviews in sharing their memories of the early days of the development of liquid crystal displays. Jacques Friedel recalled his grandfather Georges, and also his own studies in the liquid crystal field, while Yves Bouligand pointed us towards the long-ignored theoretical contribution of François Grandjean. The late Frank Leslie carefully explained the background to his work on the continuum theory of liquid crystals, but unfortunately did not live long enough to peruse the result. Tomas Carlsson also transmitted some of his insights in this area, as well as information on Björndahl and Oseen. Maxim Tomilin and Victor Reshetnyak were extremely helpful in putting us in touch with the Russian literature, and in transmitting memories from the Frederiks and Tsvetkov groups. Hiro Kawamoto and Kazu Toriyama helped us to reach some appreciation of the great contributions of Japanese science to the development of displays, and we are grateful to them. The authors also greatly appreciated the advice of Mark Warner concerning the contributions of Paul Flory to the theory of liquid crystals. The biographies of scientists whose work is included have been compiled from many different sources. We also thank all authors who have been kind enough to send us brief descriptions of their lives; we hope that our (minor) rewriting of their life stories meets with their satisfaction.

Preliminary versions of essays or translations have been read by Heinrich Arnold, Joe Castellano, Noel Clark, Jerry Ericksen, Heino Finkelmann, Pierre-Gilles de Gennes, George Heilmeyer, Maurice Kléman, Sven Lagerwall, Vittorio Luzzati, Bob Meyer, Peter Raynes, Martin Schadt, John Seddon, Joachim Stauff, Richard Williams and Louis Zanon. Karl Hiltrop was generous with helpful advice concerning the history of lyotropic liquid crystal research. We are most grateful for their comments, but of course absolve them of any responsibility for errors of fact or interpretation, which remains exclusively that of the authors. We are also indebted to the families of the late Horst Sackmann and Hans Kelker for useful comments on the circumstances of their investigations on liquid crystals.

This volume appears in the Liquid Crystal Series, for which the Series Editors are George Gray and John Goodby. We are grateful to both Series Editors for their support and encouragement in guiding this book to publication. We must thank particularly George Gray who has encouraged the authors during the gestation of this volume. He has been generous with his recollections, and vigorously contributed ideas for the book. He has read many drafts of the essays and translations, finding and correcting innumerable errors and infelicities. For all this, we thank him, but emphasise that the final responsibility for remaining errors rests

with the authors. Our ‘minder’ at Taylor and Francis over the period of the preparation of this collection has been Janie Wardle, and we thank her also for her patient help in guiding us towards a final product. We are also extremely grateful to Anita Ananda and her production team at Integra-India for their effort in typesetting an extremely non-standard text.

TJS finally wishes to thank his wife Celia and his children Ben and Rachel for their patience in allowing family time to be diverted for so long into the task of compiling this collection. Well might they protest that this was a never-ending task whose fruits they might never live to see. It is to be hoped that this prediction at least will turn out to be false! DAD, as one of the ‘co-opted’ authors, wishes to thank the initiating author Tim Sluckin for the opportunity to participate in this particular literary venture. These thanks are for the chance to have spent many leisure hours translating, writing and searching the stacks of his two universities of Southampton and Sheffield. Time thus spent might otherwise have been spent with his family, to whom thanks are also due for their understanding and forbearance. HS thanks his family and friends for mental support and tolerating his absence during his dive into the interesting history of liquid crystals.

Southampton, Münstertal, January 2003

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PREFACE

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