This Page Intentionally Left Blank
Handbook of Liquid Crystals

D. Demus, J. Goodby, G. W. Gray, H.-W. Spiess, V. Vill

Vol. 1: Fundamentals
Vol. 2 A: Low Molecular Weight Liquid Crystals I
Vol. 2 B: Low Molecular Weight Liquid Crystals II
Vol. 3: High Molecular Weight Liquid Crystals

Further title of interest: J. L. Serrano: Metallomesogens

ISBN 3-527-29296-9
Handbook
of Liquid Crystals
The Editors

D. Demus
studied chemistry at the Martin-Luther-University, Halle, Germany, where he was also awarded his Ph. D. In 1981 he became Professor, and in 1991 Deputy Vice-Chancellor of Halle University. From 1992–1994 he worked as a Special Technical Advisor for the Chisso Petrochemical Corporation in Japan. Throughout the period 1984–1991 he was a member of the International Planning and Steering Committee of the International Liquid Crystal Conferences, and was a non-executive director of the International Liquid Crystal Society. Since 1994 he is active as a Scientific Consultant in Halle. He has published over 310 scientific papers and 7 books and he holds 170 patents.

J. W. Goodby
studied for his Ph. D. in chemistry under the guidance of G. W. Gray at the University of Hull, UK. After his post-doctoral research he became supervisor of the Liquid Crystal Device Materials Research Group at AT&T Bell Laboratories. In 1988 he returned to the UK to become the Thorn-EMI/STC Reader in Industrial Chemistry and in 1990 he was appointed Professor of Organic Chemistry and Head of the Liquid Crystal Group at the University of Hull. In 1996 he was the first winner of the G. W. Gray Medal of the British Liquid Crystal Society.

G. W. Gray
studied chemistry at the University of Glasgow, UK, and received his Ph. D. from the University of London before moving to the University of Hull. His contributions have been recognised by many awards and distinctions, including the Leverhulme Gold Medal of the Royal Society (1987), Commander of the Most Excellent Order of the British Empire (1991), and Gold Medallist and Kyoto Prize Laureate in Advanced Technology (1995). His work on structure/property relationships has had far reaching influences on the understanding of liquid crystals and on their commercial applications in the field of electro-optical displays. In 1990 he became Research Coordinator for Merck (UK) Ltd, the company which, as BDH Ltd, did so much to commercialise and market the electro-optic materials which he invented at Hull University. He is now active as a Consultant, as Editor of the journal “Liquid Crystals” and as author/editor for a number of texts on Liquid Crystals.
H. W. Spiess
studied chemistry at the University of Frankfurt/Main, Germany, and obtained his Ph. D. in physical chemistry for work on transition metal complexes in the group of H. Hartmann. After professorships at the University of Mainz, Münster and Bayreuth he was appointed Director of the newly founded Max-Planck-Institute for Polymer Research in Mainz in 1984. His main research focuses on the structure and dynamics of synthetic polymers and liquid crystalline polymers by advanced NMR and other spectroscopic techniques.

V. Vill
studied chemistry and physics at the University of Münster, Germany, and acquired his Ph. D. in carbohydrate chemistry in the group of J. Thiem in 1990. He is currently appointed at the University of Hamburg, where he focuses his research on the synthesis of chiral liquid crystals from carbohydrates and the phase behavior of glycolipids. He is the founder of the LiqCryst database and author of the Landolt-Börnstein series Liquid Crystals.
List of Contributors

Volume 2B, Low Molecular Weight Crystals II

Boden, N.; Movaghar, B. (IX)
Centre for Self-Organising Molecular Systems (SOMS)
Dept. of Chemistry
University of Leeds
Leeds LS9 9JT
U.K.

Bushby, R. J. (VII)
University of Leeds
Leeds LS2 9JT
U.K.

Cammidge, A. N. (VII)
University of East Anglia
Norwich NR4 7TJ
U.K.

Chandrasekhar, S. (VIII)
Centre for Liquid Crystal Research
P. O. Box 1329
Jalahalli
Bangalore – 560 013
India

Diele, S.; Göring, P. (XIII)
Martin-Luther-Universität Halle-Wittenberg
FB Chemie
Inst. f. Physikal. Chemie
06099 Halle
Germany

Fukuda, A.; Miyachi, K. (VI:3)
Shinshu University
Faculty of Textile Science and Technology
Dept. of Kansei Engineering
Tokida 3-15-1, Ueda-shi
Nagano-ken 386
Japan

Giroud, A.-M. (XIV)
Chimie de Coordination
Unité de Recherche Associée au CNRS N. 1194
CEA Grenoble-DRFMC/SCIB
17, rue des Martyrs
38054 Grenoble Cedex
France

Imrie, C. T. (X)
University of Aberdeen
Dept. of Chemistry
Meston Walk,
Old Aberdeen AB24 3UE
U.K.

Kato, T. (XVII)
University of Tokyo
Institute of Industrial Science
7-22-1 Roppongi, Minato-ku
Tokyo 106
Japan
List of Contributors

Kelly, S. M. (VI:1)
The University of Hull
Liquid Crystals & Advanced Organic Materials Research Group
Dept. of Chemistry
Hull HU6 7RX
U.K.

Lagerwall, S. T. (VI:2)
Chalmers University of Technology
Physics Department
Liquid Crystal Group
41296 Göteborg
Sweden

Luckhurst, G. R. (X)
University of Southampton
Dept. of Chemistry
Highfield
Southampton SO17 1BJ
U.K.

Lydon, J. E. (XVIII)
University of Leeds
Dept. of Biochemistry & Molecular Biology
Leeds LS2 9JT
U.K.

Malthête, J. (XII)
Institut Curie
Section de Recherche
UMR – CNRS 168
11, Rue Pierre et Marie Curie
75231 Paris Cedex 05
France

Nguyen, H. T.; Destrade, C. (XII)
Centre de Recherche Paul Pascal
Avenue A. Schweitzer
33600 Pessac
France

Praefcke, K.; Singer, D. (XVI)
TU Berlin
IOC
Straße des 17. Juni 124
10623 Berlin
Germany

Sadashiva, B. K. (XV)
Raman Research Institute
CV Raman Avenue
Bangalore – 560 080
India

Weissflog, W. (XI)
Max-Planck-Gesellschaft
Arbeitsgruppe Flüssigkristalline Systeme
Martin-Luther-Universität
Mählpforte 1
06108 Halle
Germany
Outline

Volume 1

Chapter I: Introduction and Historical Development .............................................. 1
George W. Gray

Chapter II: Guide to the Nomenclature and Classification of Liquid Crystals ........... 17
John W. Goodby and George W. Gray

Chapter III: Theory of the Liquid Crystalline State ........................................ 25
  1 Continuum Theory for Liquid Crystals ......................................................... 25
     Frank M. Leslie
  2 Molecular Theories of Liquid Crystals .......................................................... 40
     M. A. Osipov
  3 Molecular Modelling ...................................................................................... 72
     Mark R. Wilson

Chapter IV: General Synthetic Strategies ......................................................... 87
Thies Thiemann and Volkmar Ell

Chapter V: Symmetry and Chirality in Liquid Crystals ................................... 115
John W. Goodby

Chapter VI: Chemical Structure and Mesogenic Properties ............................ 133
Dietrich Demus

Chapter VII: Physical Properties ...................................................................... 189
  1 Tensor Properties of Anisotropic Materials .................................................. 189
     David Dunmur and Kazuhisa Toriyama
  2 Magnetic Properties of Liquid Crystals ......................................................... 204
     David Dunmur and Kazuhisa Toriyama
  3 Optical Properties ......................................................................................... 215
     David Dunmur and Kazuhisa Toriyama
  4 Dielectric Properties ...................................................................................... 231
     David Dunmur and Kazuhisa Toriyama
  5 Elastic Properties ........................................................................................... 253
     David Dunmur and Kazuhisa Toriyama
  6 Phase Transitions ........................................................................................... 281
6.1 Phase Transitions Theories ............................................. 281
   Philippe Barois
6.2 Experimental Methods and Typical Results .................. 310
6.2.1 Thermal Methods .................................................. 310
   Jan Thoen
6.2.2 Density .............................................................. 334
   Wolfgang Wedler
6.2.3 Metaboolemeter ..................................................... 350
   Wolfgang Wedler
6.2.4 High Pressure Investigations .................................. 355
   P. Pollmann
6.3 Fluctuations and Liquid Crystal Phase Transitions .......... 379
   P. E. Cladis
6.4 Re-entrant Phase Transitions in Liquid Crystals .......... 391
   P. E. Cladis
7 Defects and Textures .................................................. 406
   Y. Bouligand
8 Flow Phenomena and Viscosity ...................................... 454
   Frank Schneider and Herbert Knppe
9 Behavior of Liquid Crystals in Electric and Magnetic Fields .. 477
   Lev M. Blinov
10 Surface Alignment ...................................................... 535
    Blandine Jérôme
11 Ultrasonic Properties ................................................. 549
    Olga A. Kapustina
12 Nonlinear Optical Properties of Liquid Crystals ............ 569
    P. Palffy-Muhoray
13 Diffusion in Liquid Crystals ...................................... 582
    F. Noack

Chapter VIII: Characterization Methods ............................. 595
1 Magnetic Resonance .................................................. 595
   Claudia Schmidt and Hans Wolfgang Spiess
2 X-Ray Characterization of Liquid Crystals: Instrumentation . 619
   Richard H. Templer
3 Structural Studies of Liquid Crystals by X-ray Diffraction .. 635
   John M. Seddon
4 Neutron Scattering .................................................... 680
   Robert M. Richardson
5 Light Scattering from Liquid Crystals ............................ 699
   Helen F. Gleeson
6 Brillouin Scattering from Liquid Crystals ....................... 719
   Helen F. Gleeson
7 Mössbauer Studies of Liquid Crystals ............................. 727
   Helen F. Gleeson
### Chapter IX: Applications

1. **Displays** ........................................ 731
   - *Ian C. Sage*

2. **Nondisplay Applications of Liquid Crystals** .................................. 763
   - *William A. Crossland and Timothy D. Wilkinson*

3. **Thermography Using Liquid Crystals** ........................................... 823
   - *Helen F. Gleeson*

4. **Liquid Crystals as Solvents for Spectroscopic, Chemical Reaction, and Gas Chromatographic Applications** ........................................... 839
   - *William J. Leigh and Mark S. Workentin*

### Index Volume 1 ........................................ 897

---

### Volume 2A

**Part I: Calamitic Liquid Crystals** ........................................ 1

**Chapter I: Phase Structures of Calamitic Liquid Crystals** .................................. 3
   - *John W. Goodby*

**Chapter II: Phase Transitions in Rod-Like Liquid Crystals** .......................... 23
   - *Daniel Guillon*

**Chapter III: Nematic Liquid Crystals** ........................................ 47
   1. **Synthesis of Nematic Liquid Crystals** ....................................... 47
      - *Kenneth J. Toyne*
   2. **Physical Properties** ........................................... 60
   2.1 **Elastic Properties of Nematic Liquid Crystals** .......................... 60
      - *Ralf Stannarius*
   2.2 **Dielectric Properties of Nematic Liquid Crystals** ...................... 91
      - *Horst Kresse*
   2.3 **Diamagnetic Properties of Nematic Liquid Crystals** ...................... 113
      - *Ralf Stannarius*
   2.4 **Optical Properties of Nematic Liquid Crystals** .......................... 128
      - *Gerhard Pelzl*
   2.5 **Viscosity** ........................................ 142
      - *Herbert Knappe and Frank Schneider*
   2.6 **Dynamic Properties of Nematic Liquid Crystals** .......................... 170
      - *R. Blinc and I. Muševič*
   3. **Applications** ........................................ 199
   3.1 **TN, STN Displays** ........................................ 199
      - *Harald Hirschmann and Volker Reiffenrath*
   3.2 **Active Matrix Addressed Displays** ........................................ 230
      - *Eiji Kaneko*
Chapter IV: Chiral Nematic Liquid Crystals
1 The Synthesis of Chiral Nematic Liquid Crystals
   Christopher J. Booth
2 Chiral Nematics: Physical Properties and Applications
   Harry Coles

Chapter V: Non-Chiral Smectic Liquid Crystals
1 Synthesis of Non-Chiral Smectic Liquid Crystals
   John W. Goodby
2 Physical Properties of Non-Chiral Smectic Liquid Crystals
   C. C. Huang
3 Nonchiral Smectic Liquid Crystals – Applications
   David Coates

Volume 2B

Part 2: Discotic Liquid Crystals

Chapter VI: Chiral Smectic Liquid Crystals
1 Synthesis of Chiral Smectic Liquid Crystals
   Stephen M. Kelly
2 Ferroelectric Liquid Crystals
   Sven T. Lagerwall
3 Antiferroelectric Liquid Crystals
   Kouichi Miyachi and Atsuo Fukuda

Chapter VII: Synthesis and Structural Features
   Andrew N. Cammidge and Richard J. Bushby

Chapter VIII: Discotic Liquid Crystals: Their Structures and Physical Properties
   S. Chandrasekhar

Chapter IX: Applicable Properties of Columnar Discotic Liquid Crystals
   Neville Boden and Bijou Movaghar
Part 3: Non-Conventional Liquid-Crystalline Materials

Chapter X: Liquid Crystal Dimers and Oligomers

Chapter XI: Laterally Substituted and Swallow-Tailed Liquid Crystals

Chapter XII: Phasmids and Polycatenar Mesogens

Chapter XIII: Thermotropic Cubic Phases

Chapter XIV: Metal-containing Liquid Crystals

Chapter XV: Biaxial Nematic Liquid Crystals

Chapter XVI: Charge-Transfer Systems

Chapter XVII: Hydrogen-Bonded Systems

Chapter XVIII: Chromonics

Index Volumes 2A and 2B.

Volume 3

Part 1: Main-Chain Thermotropic Liquid-Crystalline Polymers