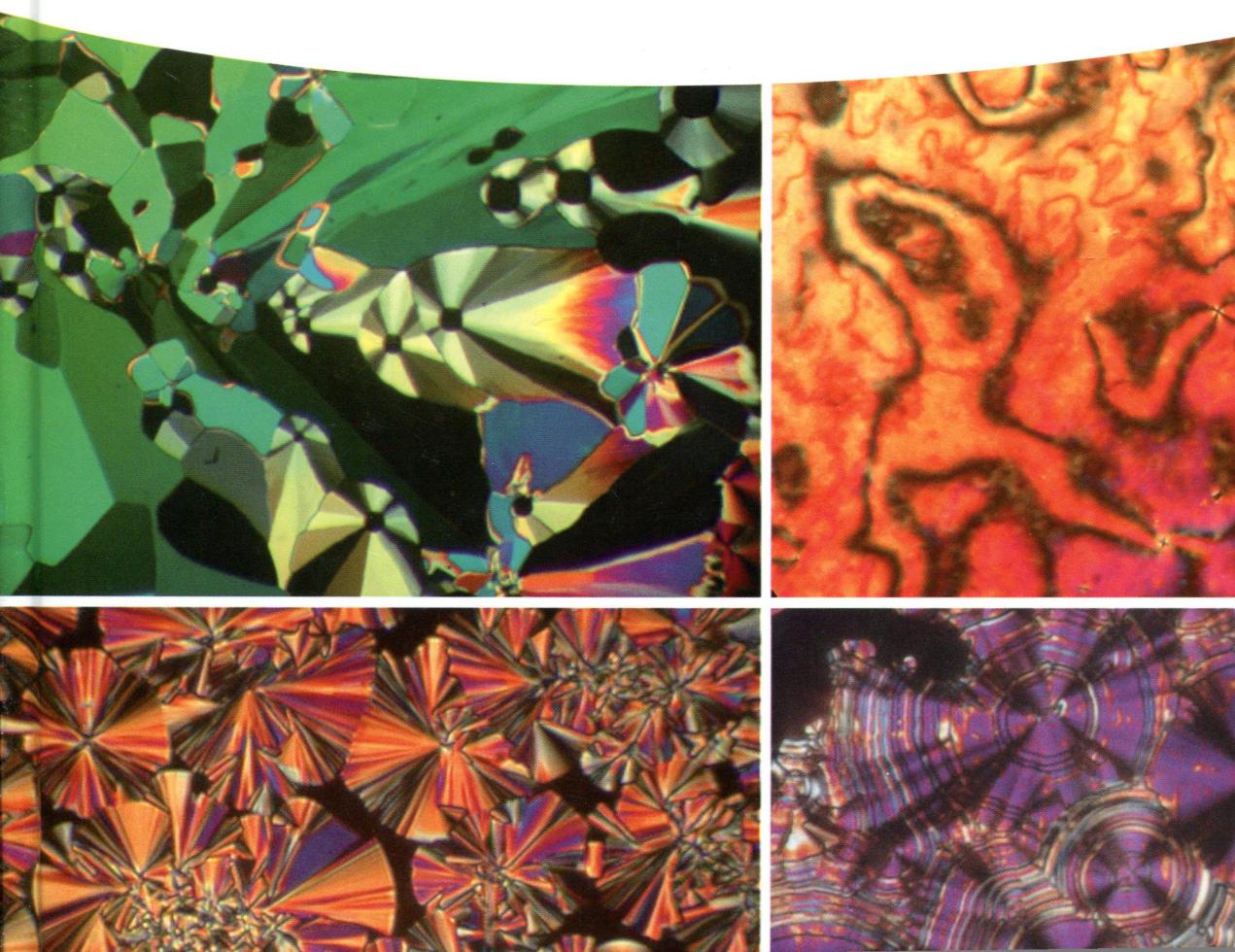


Edited by J.W. Goodby, P.J. Collings, T. Kato,  
C. Tschierske, H.F. Gleeson, P. Raynes

# Handbook of Liquid Crystals

Volume 6:  
Nanostructured and Amphiphilic Liquid Crystals  
Second, Completely Revised and Enlarged Edition



*Edited by John W. Goodby, Peter J. Collings, Takashi Kato,  
Carsten Tschierske, Helen F. Gleeson, and Peter Raynes*

## **Handbook of Liquid Crystals**

Volume 6: Nanostructured and Amphiphilic Liquid Crystals

*8 Volume Set: Second, completely revised and greatly enlarged  
edition*

**WILEY-VCH**  
Verlag GmbH & Co. KGaA

## The Editors

### ***John W. Goodby***

University of York  
Dept. of Chemistry  
Heslington  
York YO10 5DD  
UK

### ***Peter J. Collings***

Swarthmore College  
Dept. of Physics & Astronomy  
Swarthmore, PA 19081  
USA

### ***Takashi Kato***

University of Tokyo  
Dept. of Chemistry and Biotechnol.  
School of Engineering  
Tokyo 113-8656  
Japan

### ***Carsten Tschierske***

Martin-Luther University Halle-Wittenberg  
Dept. of Chemistry  
Kurt-Mothes-Str. 2  
06120 Halle/Saale  
Germany

### ***Helen F. Gleeson***

University of Manchester  
School of Physics and Astronomy  
Manchester M13 9PL  
UK

### ***Peter Raynes***

University of York  
Dept. of Chemistry  
Heslington  
York YO10 5DD  
UK

All books published by Wiley-VCH are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

**Library of Congress Card No.:** applied for

**British Library Cataloguing-in-Publication Data**

A catalogue record for this book is available from the British Library.

**Bibliographic information published by the Deutsche Nationalbibliothek**

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <<http://dnb.d-nb.de>>.

© 2014 Wiley-VCH Verlag & Co. KGaA,  
Boschstr. 12, 69469 Weinheim, Germany

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photostriping, microfilm, or any other means – nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

**Print ISBN:** 978-3-527-32773-7

**eBook ISBN:** 978-3-527-67140-3

**Typesetting** Laserwords Private Limited,  
Chennai, India

**Printing and Binding** Strauss GmbH,  
Mörlenbach, Germany

**Cover Design** Schulz Grafik-Design,  
Fußgönheim

Printed in Germany

Printed on acid-free paper

## Contents

Preface *XIII*

About the Editors *XVII*

List of Contributors *XXI*

### Part 1 Nanostructured Liquid Crystals 1

<b>1</b>	<b>Liquid-Crystalline Gels 3</b>
	<i>Kazuhiro Yabuuchi and Takashi Kato</i>
1.1	General Structure of Liquid-Crystalline Gels 3
1.1.1	Physical Gels and Low-Molecular-Weight Gelators 3
1.1.2	Gelation of Liquid Crystals 3
1.2	Phase-Separated Structures of LC Gels 10
1.2.1	Phase Transition and Morphology 10
1.2.1.1	Type I ( $T_{\text{sol-gel}} > T_{\text{iso-lc}}$ ) 10
1.2.1.2	Type II ( $T_{\text{sol-gel}} < T_{\text{iso-lc}}$ ) 12
1.2.2	LC Gels with Various LC Structures 12
1.2.2.1	Nematic Gels 12
1.2.2.2	Cholesteric Gels 13
1.2.2.3	Smectic Gels 13
1.2.2.4	Discotic Gels 13
1.3	Function of LC Gels 14
1.3.1	Electrooptical Materials 14
1.3.1.1	Electrooptical Switching in TN Mode 14
1.3.1.2	Electrooptical Switching in Light-Scattering Mode 16
1.3.2	Rewritable Information Recording 18
1.3.2.1	Formation of Bistable LC Gel Structures Using Electric Fields 18
1.3.2.2	Photocontrol of LC Gel Structures 19
1.3.3	Conductive/Semiconductive Materials 20
1.3.3.1	Hole-Transporting LC Gels 20
1.3.3.2	Conductive Self-Assembled Fibers 21
1.3.4	Luminescent Materials 22
1.3.4.1	Polarized Luminescence from Aligned Fibers of Photoluminescent Gelators 22

1.3.4.2	Electrically Switchable Photoluminescence of LC Gels	22
1.4	Conclusion	23
	References	23
<b>2</b>	<b>Nanoparticles: Additives and Building Blocks for Liquid Crystal Phases</b>	<b>27</b>
	<i>S. Umadevi, V. Ganesh, and Torsten Hegmann</i>	
2.1	Introduction	27
2.2	Nanoparticle Chemistry	28
2.2.1	Metal (Gold) Nanoparticles	28
2.2.2	Semiconductor Nanoparticles	33
2.3	Nanoparticles as Additives in Liquid Crystals	35
2.3.1	Quasi-Spherical Nanoparticles	35
2.3.2	Metal and Semiconductor Nanorods	59
2.4	Nanoparticle Self-Assembly and Liquid Crystal Phase Formation	62
2.5	Conclusions	68
	References	68
<b>3</b>	<b>Mineral Liquid Crystals: Liquid-Crystalline Suspensions of Mineral Nanoparticles</b>	<b>77</b>
	<i>Patrick Davidson</i>	
3.1	Introduction	77
3.2	Techniques	78
3.3	Colloidal Stability, Gelation, and Solvent Effects	80
3.4	Theoretical Considerations	81
3.5	Nanowires	82
3.6	Nanorods	85
3.7	Sheets	87
3.8	Disks	92
3.9	Conclusion	94
	References	94
<b>4</b>	<b>Carbon Nanotubes in Liquid Crystals</b>	<b>99</b>
	<i>Jan Lagerwall and Giusy Scalia</i>	
4.1	Introduction	99
4.2	A Short Introduction to Carbon Nanotubes	100
4.3	Dispersion of Carbon Nanotubes	104
4.4	Liquid Crystal Phases of Carbon Nanotubes	108
4.5	Liquid Crystal Phases of Graphene	113
4.6	Carbon Nanotubes in Thermotropic Liquid Crystals	114
4.7	Carbon Nanotubes Aligned by Lyotropic Liquid Crystals	119
4.8	Carbon Nanotubes in Liquid Crystalline Polymers or Polymerized Liquid Crystals	124
4.9	Conclusions and Outlook	128
	References	129

<b>5</b>	<b>Nematic and Chiral Nematic Liquid Crystals in Confined Geometries: Elementary Background with Selected Examples</b>	<b>139</b>
	<i>Miha Ravnik and Slobodan Žumer</i>	
5.1	Introduction	139
5.2	Confined Liquid Crystals: Anchoring, Elasticity, Defects, and Typical Spatial Scale	140
5.3	Nematic and Cholesteric Droplets	143
5.4	Capillary Confined Liquid Crystals	147
5.5	Liquid Crystals in Porous and Random Porous Media	150
5.6	Liquid Crystal Shells	152
5.7	Methods to Study Confinement	153
5.8	Challenges and Interesting Directions in Confined Nematics	155
5.8.1	Frustration by Complex Optical Fields	155
5.8.2	Confined Liquid Crystal Sensors	155
5.8.3	“Active” Confinement	156
5.9	Concluding Remarks	156
	Acknowledgments	157
	References	157
<b>6</b>	<b>Colloid Crystals in Nematic Liquid Crystals</b>	<b>161</b>
	<i>Igor Mušević</i>	
6.1	Introduction	161
6.2	Topological Dipoles and Quadrupoles	163
6.3	Nematic-Mediated Forces between Dipolar and Quadrupolar Colloidal Particles	165
6.4	Optical Tweezing and Manipulation of Colloids	169
6.5	2D and 3D Colloidal Crystals and Superstructures	171
6.6	Entanglement of Liquid Crystal Colloids	173
6.7	Shape- and Size-Dependent Colloidal Interactions	176
6.8	Chiral Nematic and Blue-Phase Colloids	179
6.9	Colloids at Liquid Crystal Interfaces and Smectic Membranes	181
6.10	Other Observations and Colloid-Related Structures	182
	References	183
<b>7</b>	<b>Virus Particle-Based Liquid Crystals</b>	<b>193</b>
	<i>John Lydon</i>	
7.1	Introduction	193
7.1.1	History	193
7.1.2	Treatment of Virus Infections	195
7.1.3	Bacteriophage	197
7.1.4	Utilizing Viruses	198
7.2	The Rationale for Virus Structures: The Coding Deficit	198
7.3	TMV – Mesophase Formation	199
7.4	Structure of the TMV Capsid	203
7.4.1	Electron Microscopy	203

7.4.2	X-Ray Diffraction	204
7.5	How the TMV Virus Invades the Cell	204
7.5.1	The TMV Genome	205
7.6	The Self-Assembly of TMV	206
7.6.1	<i>In vitro</i> Assembly	206
7.6.2	<i>In vivo</i> Assembly	208
7.6.3	Confirmation of the Mechanism	209
7.7	TMV as a Test Case for the Onsager Theory	209
7.8	Nematic or Cholesteric?	211
7.9	Phase Behavior of Virus Rod/Polymer Sphere Mixtures	213
7.10	Filamentous Virus Suspensions as Materials for Studying Mesophases and Self-Ordering Systems	215
7.11	Icosahedral Viruses	215
7.11.1	Introduction	215
7.11.2	The Structure of Icosahedral Viruses with More Than 60 Capsomeres	216
7.11.3	Iridescent Viruses	217
7.11.4	The Utilization of Viruses as Templates for the Construction of Nanostructures	219
7.11.5	Filamentous Viruses	220
7.11.6	Quantum Dots	221
7.11.7	Opals and Inverse Opals	222
7.12	Last Words	224
	Glossary	224
	References	225

## Part 2 Amphiphilic Liquid Crystals 229

<b>8</b>	<b>Ionic Liquid Crystals</b>	231
	<i>Markus Mansueti and Sabine Laschat</i>	
8.1	Introduction	231
8.2	Historical Remarks	232
8.3	Pyridinium and Viologen Ionic Liquid Crystals	232
8.4	Guanidinium-Based Ionic Liquid Crystals	239
8.5	ILC with a Quaternary Ammonium Moiety	247
8.6	Imidazolium-Based ILCs	252
8.7	Miscellaneous	268
8.8	Conclusion	273
	References	275
<b>9</b>	<b>Amphitropic Hydrogen-Bonded Liquid Crystals</b>	281
	<i>Edward J. Davis and John W. Goodby</i>	
9.1	Introduction	281
9.2	Materials with One Head and One Tail	286
9.2.1	Aliphatic Diols	286

9.2.2	Carboxylic Acids	290
9.2.3	Amphiphilic Materials with Poly-ol Head Groups	291
9.2.4	Pyranose Systems	296
9.2.5	Furanose Systems	302
9.3	Amphiphiles with One Head and Two Tails	304
9.3.1	Cerebrosides	304
9.3.2	Glycolipids Associated with Archaebacteria	307
9.4	Bolaamphiphiles – Heads Groups Joined by a Chain	307
9.5	Complex Bolaphiles and Quasi-Macrocyclic Systems	309
9.6	Amphitropic Hydrogen-Bonded Polymeric Systems	313
9.7	Summary	314
	References	314
<b>10</b>	<b>Lipid Self-Assembly</b>	<b>317</b>
	<i>Linda Susan Hirst</i>	
10.1	Introduction	317
10.2	Lipid Structure and Assembly	318
10.3	Lipid Nomenclature	319
10.3.1	Phospholipids	321
10.3.2	Sphingolipids and Glycolipids	321
10.3.3	Sterols	322
10.4	Lipid Phase Behavior	322
10.4.1	The Lamellar Phase and Bilayer Structures	325
10.4.2	Thermotropic Lipid Phases	328
10.4.3	Experimental Characterization	331
	References	333
<b>11</b>	<b>Liquid Crystal Crown Ethers and Related Compounds</b>	<b>335</b>
	<i>Martin Kaller, Angelika Baro, and Sabine Laschat</i>	
11.1	Introduction	335
11.2	Terminally Attached Crown Ethers with Rodlike Substituents	336
11.2.1	Monomeric Compounds	336
11.2.2	Polymeric Compounds	339
11.2.3	Applications	342
11.3	Rodlike Molecules with Laterally Attached Crown Ethers	343
11.4	Central Crown Ethers with Terminally Attached Rodlike and Polycatenar Substituents	346
11.4.1	Monomeric Compounds	346
11.4.1.1	Schiff Bases and Azo Compounds	346
11.4.1.2	Diazacrowns	347
11.4.2	Polymeric Compounds	352
11.5	Terminal Crown Ethers with One Taper-Shaped Substituent	352
11.5.1	Monomeric Compounds	352
11.5.2	Polymeric Compounds and Possible Applications	357

11.6	Central Crown Ethers with More than One Peripheral Substituent	358
11.6.1	Polysubstituted Macroyclic Polyamines	358
11.6.2	Crown Ethers with Several Taper- or Disk-Shaped Substituents	363
11.7	Crownlike Cyclophanes	367
11.8	Metallomesogens	369
11.9	Conclusion	372
	References	372
<b>12</b>	<b>Lyotropic Surfactant Liquid Crystals: Micellar Systems</b>	<b>377</b>
	<i>Abdullah Alfutimie, Robin Curtis, and Gordon J. T. Tiddy</i>	
12.1	Introduction	377
12.2	Surfactant Solutions ( $L_1$ , Micelles)	378
12.3	Surfactant Lyotropic Liquid Crystals	384
12.3.1	Lamellar Phase ( $L_a$ )	384
12.3.2	Hexagonal Phase ( $H_1$ and $H_2$ )	385
12.3.3	Cubic Phases (I and V)	386
12.3.4	Intermediate Phases	387
12.3.5	Nematic Phases ( $N_d$ and $N_c$ )	387
12.3.6	Why Mesophases Form?	388
12.4	Gel Phases ( $L_\beta$ )	390
12.5	Phase Behavior of Liquid Crystals	392
12.5.1	Phase Behavior of Normal Liquid Crystals	393
12.5.2	Surfactant/Water Systems – Recent Results	394
12.5.2.1	Single Surfactant/Water Systems	394
12.5.2.2	Mixed Surfactant Systems	405
12.5.2.3	Surfactant/Oil/Water Systems	410
12.6	Concluding Comments	416
	References	417
<b>13</b>	<b>Self-Assembled Monolayers of Liquid Crystals on Surfaces</b>	<b>421</b>
	<i>Stephen D. Evans and Jonathan P. Bramble</i>	
13.1	Self-Assembled Monolayers: an Introduction	421
13.2	Self-Assembled Monolayers of Calamitic LC Derivatives	422
13.2.1	SAMs of Mercaptobiphenyls Containing Moieties	422
13.2.2	SAMs of Cyano-Biphenyl and Cyano-Terphenyl Containing Moieties	424
13.3	Photoswitchable “Command” Surfaces	428
13.3.1	Stilbene SAMs	428
13.3.2	Azobenzene-Functionalized SAMs	429
13.4	Self-Assembled Monolayers of Discotic LC Derivatives	431
13.5	Summary	433
	Acronyms	433
	References	434

<b>14</b>	<b>Chromonic Liquid Crystals</b>	439
	<i>John Lydon</i>	
14.1	Introduction	439
14.1.1	Preface	439
14.1.2	Early History	441
14.1.3	The “Classical” Picture of Chromonic Phases	442
14.2	The Characterization of Chromonic Phases	445
14.2.1	Optical Textures and Phase Diagrams	445
14.2.2	X-Ray Diffraction Patterns	450
14.2.3	Chromonic Column Structure	452
14.2.4	Spectroscopy	453
14.2.5	Aggregation Numbers	454
14.2.6	Optical Properties: Refractive Index and Absorption	454
14.2.7	The Planarity of Chromonogenic Molecules	456
14.2.8	Computer modelling	456
14.3	The Range of Chromonic Mesogens	460
14.4	Recent Studies of Chromonic Systems	460
14.4.1	Sunset Yellow FCF	460
14.4.2	Bordeaux Dye	462
14.4.3	Nonionic Chromonic Systems	463
14.4.4	Nonaqueous Solvents	465
14.4.5	Chimney and Brick wall structures	465
14.5	Nucleic Acids DNA and RNA	467
14.6	Exploitation of Chromonic Phases	468
14.6.1	Assay of Chiral Solutes	469
14.6.2	The Production of Aligned Films	469
14.6.3	Photoalignment	471
14.6.4	Reusable Templates	472
14.6.5	E-Type Polarizers	473
14.6.6	Biosensors	474
14.7	Complex Chromonics	474
14.7.1	Graphitic Nanotubes	475
14.7.2	Ribbons and Double-Layered Tubes of Cyanine Dyes	476
14.7.3	Novel Vesicles	477
14.8	Organic Electronics	478
14.9	Last Word	479
	Acknowledgments	479
	References	480
	<b>Index</b>	485