Contents

Preface *xi*

1 Room-Temperature Liquid Dyes *1*
Bhawani Narayan and Takashi Nakanishi
1.1 Introduction *1*
1.2 Design Strategy: Alkyl Chain Engineering *2*
1.3 Alkylated π-Molecular Liquids *3*
1.3.1 Carbazoles *3*
1.3.2 Azobenzenes *5*
1.3.3 Naphthalenes *6*
1.3.4 Anthracenes *6*
1.3.5 Pyrenes *8*
1.3.6 π-Conjugated Oligomers *10*
1.3.6.1 Oligo-(*p*-phenylenevinylene)s (OPVs) *10*
1.3.6.2 Oligo-(*p*-phenyleneethylene)s (OPEs) *11*
1.3.6.3 Benzothiadiazoles (BTDs) *12*
1.3.7 Porphyrins *12*
1.3.8 Fullerenes *12*
1.4 Alkylsilane-Chain-Appended π-Molecular Liquids *13*
1.4.1 Triarylamines *14*
1.4.2 Phthalocyanines *15*
1.4.3 Oligofluorenes *15*
1.5 Analytical Tools for Functional Molecular Liquids *16*
1.5.1 Analytical Tools for Bulk Physical Properties *16*
1.5.1.1 Structural Analysis *16*
1.5.1.2 Microscopy Techniques *16*
1.5.1.3 Rheology *16*
1.5.1.4 Calorimetric Techniques *17*
1.5.2 Analytical Tools for Spectroscopic Properties *17*
1.5.2.1 UV–vis Analysis *17*
1.5.2.2 Fluorescence Measurements *17*
1.5.2.3 Fluorescence Lifetime Analysis *17*
1.5.2.4 FTIR Measurements *17*
1.6 Conclusion *18*
References *18*

2 Low-Melting Porphyrins and Their Photophysical Properties *21*
Agnieszka Nowak-Król and Daniel T. Gryko
2.1 Introduction *21*
2.2 Liquid Porphyrins *22*
2.3 Low-Melting *trans*-A_2B_2-Arylethynyl Porphyrins *28*
2.4 Liquid Crystalline *trans*-A_2B_2-Arylethynyl Porphyrins *31*
2.5 Bis-porphyrins *31*
2.6 Low-Melting Corroles *34*
2.7 Summary and Outlook *34*
References *35*

3 Porous Liquids *39*
Stuart L. James and Ben Hutchings
3.1 Introduction *39*
3.2 Porosity in Solids *40*
3.3 Porosity in Liquids *41*
3.4 Porous Liquids Reported in the Literature *43*
3.4.1 Type 1 *43*
3.4.2 Type 2 *46*
3.4.3 Type 3 *48*
3.4.4 Other Types of Porous Liquids and Theoretical Studies *48*
3.5 Opportunities for Applications and Current Challenges *49*
3.6 Concluding Remarks *50*
References *50*

4 Cyclic Host Liquids for the Formation of Rotaxanes and Their Applications *53*
Tomoki Ogoshi, Takahiro Kakuta, and Tada-aki Yamagishi
4.1 Introduction *53*
4.2 Liquid Pillar[*n*]arenes at Room Temperature *54*
4.2.1 Synthesis and Structure of Pillar[*n*]arenes *54*
4.2.2 Versatile Functionality of Pillar[*n*]arenes *55*
4.2.3 Molecular Design to Produce Liquid-State Macrocyclic Hosts *56*
4.2.3.1 Pillar[*n*]arenes *56*
4.2.3.2 Cyclodextrins *58*
4.2.3.3 Crown Ethers *60*
4.2.3.4 Calix[*n*]arenes and Cucurbit[*n*]urils *60*
4.3 Complexation of Guest Molecules by Pillar[5]arenes *61*
4.3.1 Host Properties of Pillar[5]arenes *61*
4.3.2 Complexation of Guest Molecules in Liquid Pillar[5]arenes *62*
4.4 High Yield Synthesis of [2]Rotaxane and Polyrotaxane Using Liquid Pillar[5]arenes as Solvents *63*
4.5 Conclusion and Remarks *70*
References *71*

5 Photochemically Reversible Liquefaction/Solidification of Sugar-Alcohol Derivatives *75*
Haruhisa Akiyama
5.1 Introduction *75*
5.2 Mechanism of the Phase Transition Between Liquid and Solid State *76*
5.3 Effect of Molecular Structure *79*
5.3.1 Number of Azobenzene Units *79*
5.3.2 Alkyl Chain Length *80*
5.3.3 Mixed Arms *82*
5.3.4 Structure of Sugar Alcohol *83*
5.4 Summary *85*
Acknowledgments *85*
References *85*

6 Functional Organic Supercooled Liquids *87*
Kyeongwoon Chung, Da Seul Yang, and Jinsang Kim
6.1 Organic Supercooled Liquids *87*
6.2 Stimuli-Responsive Organic Supercooled Liquids *88*
6.2.1 Shear-triggered Crystallization *88*
6.2.2 Scratch-Induced Crystallization of Trifluoromethylquinoline Derivatives *89*
6.2.3 Highly Sensitive Shear-Triggered Crystallization in Thermally Stable Organic Supercooled Liquid of a Diketopyrrolopyrrole Derivative *91*
6.3 Highly Emissive Supercooled Liquids *95*
6.4 Conclusion *97*
References *97*

7 Organic Liquids in Energy Systems *101*
Pengfei Duan, Nobuhiro Yanai, and Nobuo Kimizuka
7.1 Introduction *101*
7.2 Photoresponsive π-Liquids for Molecular Solar Thermal Fuels *102*
7.3 Azobenzene-Containing Ionic Liquids and the Phase Crossover Approach *107*
7.4 Photon Upconversion and Condensed Molecular Systems *113*
7.5 TTA-UC Based on the Amorphous π-Liquid Systems *114*
7.6 Photon Upconversion Based on Bicontinuous Ionic Liquid Systems *118*
7.7 Conclusion and Outlook *121*
References *122*

8 Organic Light Emitting Diodes with Liquid Emitters *127*
Jean-Charles Ribierre, Jun Mizuno, Reiji Hattori, and Chihaya Adachi
8.1 Introduction *127*
8.2 Organic Light-emitting Diodes with a Solvent-Free Liquid Organic Light-emitting Layer *129*

8.2.1 Basics of Conventional Solid-state OLEDs *129*
8.2.2 First Demonstration of a Fluidic OLED Based on a Liquid Carbazole Host *130*
8.2.3 Introduction of an Electrolyte to Improve the Liquid OLED Performance *132*
8.2.4 Liquid OLED Material Issues *134*
8.3 Microfluidic OLEDs *135*
8.3.1 Refreshable Liquid Electroluminescent Devices *135*
8.3.2 Fabrication of Microfluidic Organic Light-Emitting Devices *137*
8.3.3 Large-Area Flexible Microfluidic OLEDs *137*
8.3.4 Multicolor Microfluidic OLEDs *140*
8.3.5 Microfluidic White OLEDs *143*
8.4 Conclusions *147*
References *148*

9 Liquids Based on Nanocarbons and Inorganic Nanoparticles *151*
Avijit Ghosh and Takashi Nakanishi
9.1 Liquid Nanocarbons *151*
9.1.1 Introduction *151*
9.1.2 General Synthetic Strategies *151*
9.1.3 Liquid Fullerenes *152*
9.1.4 Liquid-Like Carbon Nanotubes *154*
9.1.5 Fluidic Graphene/Graphene Oxide *156*
9.2 Liquids Based on Inorganic Nanoparticles *158*
9.2.1 Background *158*
9.2.2 Liquid-Like Silica Nanoparticles *159*
9.2.3 Functional Colloidal Fluids *160*
9.2.4 Fluidic Functional Quantum Dots *161*
9.3 Conclusions *162*
References *164*

10 Solvent-Free Nanofluids and Reactive Nanofluids *169*
John Texter
10.1 Introduction *169*
10.1.1 Solvent-Free Nanofluids *170*
10.1.2 Simulation and Theoretical Modeling *180*
10.1.3 Reactive Solvent-Free Nanofluids *183*
10.2 Syntheses of Nanofluids *184*
10.2.1 Core–Corona–Cap Nanofluid *184*
10.2.2 Core-Free Corona–Cap Nanofluid *186*
10.2.3 Core–Corona Nanofluid *186*
10.3 UV Reactive Nanofluids *187*
10.3.1 Model Coatings and Thermomechanical Characterization *187*
10.3.2 UV Protective Coatings *191*
10.4 Polyurethane and Polyurea Coupling of Nanofluids *191*
10.4.1 Air-Cured Polyurethane Coupling with Isothiocyanate Nanofluid *192*

10.4.2 Air-Cured TDI Coupling with Amino Nanofluid *195*
10.4.3 Polyurethane Shape-Memory Materials *196*
10.4.4 PDMS-Amino Nanofluids Coupling with HMDI *197*
10.4.5 Polyurethane Coupling with Hydroxyl Nanofluid *198*
10.5 Epoxy Coupling with Amino Nanofluid *198*
10.6 Using Nanofluids to Make Composites Tougher *199*
10.6.1 Nanosilica Polyacrylate Nanocomposites *199*
10.6.2 MWCNT Polyamide Nanocomposites *200*
10.6.3 $MnSn(OH)_6$ Thread Epoxy Nanocomposites *201*
10.6.4 Graphene Oxide Epoxy Nanocomposites *201*
10.7 Summary and Future Prospects *201*
Acknowledgments *203*
References *203*

11 Solvent-Free Liquids and Liquid Crystals from Biomacromolecules *211*
Kai Liu, Chao Ma, and Andreas Herrmann
11.1 Introduction *211*
11.2 Solvent-Free Nucleic Acid Liquids *212*
11.2.1 Fabrication of Solvent-Free Nucleic Acid Liquids *212*
11.2.2 Electrical Applications Based on Solvent-Free Nucleic Acid Liquids *215*
11.3 Solvent-Free Protein Liquids *217*
11.3.1 Fabrication of Solvent-Free Protein Liquids *217*
11.3.2 Electrochemical Applications Based on Solvent-Free Protein Liquids *222*
11.3.3 Catalysis of Solvent-Free Enzyme Liquids *224*
11.4 Solvent-Free Virus Liquids *226*
11.5 Mechanism for the Formation of Solvent-Free Bioliquids *228*
11.6 Conclusions and Outlook *229*
References *230*

12 Ionic Liquids *235*
Hiroyuki Ohno
12.1 What Is Ionic Liquid? *235*
12.2 Some Physicochemical Properties *236*
12.3 Preparation *238*
12.4 IL Derivatives *239*
12.4.1 Zwitterions *239*
12.4.2 Self-Assembled ILs *239*
12.4.3 Polymers *241*
12.5 IL/Water Functional Mixture *241*
12.6 Application *243*
12.6.1 Reaction Solvents *243*
12.6.2 Electrolyte Solution *243*
12.6.3 Biomass Treatment *244*
12.6.4 Solvents for Proteins and Biofuel Cell *246*

12.7 Summary *247*
Acknowledgments *247*
References *247*

13 Room-Temperature Liquid Metals as Functional Liquids *251*
Minyung Song and Michael D. Dickey
13.1 Introduction: Room-temperature Liquid Metals *251*
13.1.1 Mercury *251*
13.1.2 Gallium-Based Alloys *252*
13.1.3 Oxide Skin on Ga Alloys *252*
13.2 Removal of Oxide Skin *252*
13.3 Patterning Techniques for Liquid Metals *253*
13.3.1 Lithography-enabled Processes *254*
13.3.2 Injection *255*
13.3.3 Subtractive *256*
13.3.4 Additive *256*
13.4 Controlling Interfacial Tension *257*
13.4.1 Surface Activity of the Oxide on Liquid Metal Droplets *258*
13.5 Applications of Liquid Metals *261*
13.6 Conclusions and Outlook *263*
References *263*

Index *273*