Types of Liquid Crystals

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The liquid-crystalline state of matter (mesomorphic state, or mesophase) is intermediate between the crystalline and liquid states, simultaneously showing some of the anisotropic properties of solids and the fluidity of liquids. In this state, materials demonstrate a tendency to flow like liquids and have some properties similar to solids. LCs may be divided into two main classes, named thermotropics and lyotropics. The importance of liquid crystals, alongside with their technical applications, lies in their role as carriers of life. In fact, fully ordered solids are a dead matter, and fully disordered liquids are also dead. But liquid crystals, as partially ordered soft matter systems, bear all qualities that had been necessary for the emergence of life. Practically all biological structures show some features pf liquid crystalline ordering.

carbon nanotubes thermotropic liquid crystals (LCs) lyotropic LCs

1. Introduction

Liquid crystal (LC) colloids constantly attract great attention from researchers. The early historical account of the problem was presented in [1]. One can also mention the recent reviews on metal oxide nanoparticles (MgO, ZnO, Fe_2O_3, Al_2O_3, Cu_2O_3, NiO, SiO_2, ZrO_2, and TiO_2) [2], semiconducting quantum dots/rods [3], and metal (Ag, Au, and Pt) nanoparticles [4][5] dispersed in LCs. The effects of the LC's material alignment induced or enhanced by incorporated nanoparticles and the methodology of developing new innovative devices based on this alignment process were recently discussed [6]. The effects of LC phase transitions on the topological defects (defect morphogenesis) induced by the colloidal particles dispersed in LCs were also recently reviewed [7].

Note that LCs may serve as a special type of host for anisotropically shaped nanoparticles such as carbon nanotubes (CNTs), as well as graphene-derived or inorganic nano-platelets [8]. These composites exhibit many intriguing properties related to the anisotropy of individual particles and self-assembled LC systems [9]. LCs can assist in the aligning of such nanoparticles, resulting in the formation of anisotropic systems with enhanced functional properties. Moreover, in such systems, the inverse alignment effects of anisometric particles on the LC's ordering can be very important. In previous years, the composites based on LCs doped with anisotropically shaped nanoparticles attracted great attention. These composites can be used for creating multifunctional devices with exceptional electronic performance.

2. Types of Liquid Crystals

The liquid-crystalline state of matter (mesomorphic state, or mesophase) is intermediate between the crystalline and liquid states, simultaneously showing some of the anisotropic properties of solids and the fluidity of liquids [10]. In this state, materials demonstrate a tendency to flow like liquids and have some properties similar to solids. LCs may be divided into two main classes, named thermotropics and lyotropics [2][6][11]. Amphotropic LCs that show both thermotropic and lyotropic phases were also identified [12][13]. For example, exhibition of amphotropic LC properties has been reported for many amino acid, peptide, phospho- and glycolipid-based LCs, with a special attention to the LC-like structure of cell membranes [14][15][16]. The properties of polymeric and elastomeric LC phases were also discussed [17][18][19][20]. These materials combine polymer network properties with LC anisotropy, and they are good candidates for stimuli-responsive reversible shape memory materials [21]. The different polymer-modified LCs (e.g., a continuous polymer matrix with the inclusion of LC droplets or a bicontinuous system of a polymer network dispersed in an LC host) also represent a great interest for different practical applications [22].

For the completeness, it can also refer to important classes of unconventional LCs. The two main categories related to supermolecular and supramolecular systems were highlighted (for a recent review, see [23]). The different types of ionic LC versatile materials (dendrimeric thermotropic, polymeric, lyotropic, zwitterionic, and mesoionic) were also identified [24][25].

2.1. Thermotropic Liquid Crystals

Thermotropic LCs demonstrate the presence of LC phases in a certain temperature range between the crystalline solid and isotropic liquid. Therefore, in these materials, the mesomorphic state formation depends on temperature. These substances with anisotropically shaped molecules demonstrate the dual characteristics of solids and liquids. They have some sort of positional or orientational order and may flow like a liquid. This duality can lead to anisotropy in optical, viscoelastic, electrical, and magnetic properties. On the basis of molecular shape, the LCs can be classified as calamitic (rod-like molecules), discotic (disc-like molecules), and bent-core (banana-shaped molecules with bent cores and flexible tails) types; other more exotic types (e.g., bowlic) have also been reported. Nowadays, huge quantities of thermotropic LC substances (more than 70,000) with different chemical compositions and phase transition temperatures have been discovered [26][27].

The main thermotropic LC phases are nematics, smectics, and cholesterics [28][29][30]. In the simplest nematic LCs, the molecules are preferentially oriented along a single director axis, but they have no positional order. In the smectic LCs phases with positional layered order, the molecules have a long-range orientational order and are organized positionally in smectic layers. In smectic A and smectic C phases, the molecules are oriented along the layer normally and at an oblique angle to the normal angle, respectively. There also exist many other types of smectic arrangements (B, D, E, F, etc.) with more complex self-organization. In the cholesteric (chiral nematic) LC phase, the director shows a helical structure and the molecules are arranged along a director axis with continuous changes of their directions in the form of a helix [28]. The helical period is typically in the range from 0.1 to 100 microns, with characteristics optimal for applications observed in more narrow ranges (10–20 μm in most cases). The more complex LC phases such as chiral nematic, chiral smectic, blue phases, and twist grain boundary phases were also identified [13], as well as most novel twist-bend and ferroelectric nematics [31][32]. The phase transitions between various LC phases can be first order, second order, or weakly first order. Nematic liquid crystals are the base of most modern displays, with OLEDs, despite recent spectacular developments, still lagging behind.

2.2. Lyotropic Liquid Crystals

In lyotropic LCs, the phase transitions are induced by changes in the temperature and concentration of dissolved amphiphilic molecules (including the hydrophobic and hydrophilic blocks) in suitable solvents. In an aqueous environment, such molecules can be self-organized in different phases depending on their molecular structure [33][34]. At temperatures above Krafft point, boundaries called CMC curves between the unimer and aggregate solution (micellar, vesicle, or microemulsions) phases appear. Typically, lyotropic LCs demonstrate the different types of long-range periodicity, with amphiphilic molecules arranged in the nematic, hexagonal, lamellar, and different intermediate (e.g., cubic) phases [35]. In a lamellar phase, bilayers with hydrophilic head groups oriented to water are formed. In a hexagonal phase, the amphiphilic molecules are arranged as infinite cylindrical structures on a hexagonal lattice. A cubic phase may exist between the lamellar and hexagonal LC phases; in this phase, the arrangement is in the form of a lipid sphere in a dense cubic lattice. These LCs can be used as efficient systems in drug delivery [36]. Water-based lyotropic LCs are common in biological and living systems [37]. The phase diagrams for many surfactant/water systems can be found in the review [34]. The anisotropic colloidal particles (rod-like, plate-like, or their hybrids) can also form lyotropic LC phases. These structures are called nanomesogen lyotropic LCs [38].

References

1. Stark, H. Physics of Colloidal Dispersions in Nematic Liquid Crystals. Phys. Rep. 2001, 351, 387–474.
2. Prakash, J.; Khan, S.; Chauhan, S.; Biradar, A.M. Metal Oxide-Nanoparticles and Liquid Crystal Composites: A Review of Recent Progress. J. Mol. Liq. 2020, 297, 112052.
3. Singh, G.; Fisch, M.; Kumar, S. Emissivity and Electrooptical Properties of Semiconducting Quantum Dots/Rods and Liquid Crystal Composites: A Review. Rep. Prog. Phys. 2016, 79, 56502.
4. Choudhary, A.; Singh, G.; Biradar, A.M. Advances in Gold Nanoparticle—Liquid Crystal Composites. Nanoscale 2014, 6, 7743–7756.
5. Ahmad, F.; Luqman, M.; Jamil, M. Advances in the Metal Nanoparticles (MNPs) Doped Liquid Crystals and Polymer Dispersed Liquid Crystal (PDLC) Composites and Their Applications—A Review. Mol. Cryst. Liq. Cryst. 2021, 731, 1–33.

6. Prakash, J.; Kumar, A.; Chauhan, S. Aligning Liquid Crystal Materials through Nanoparticles: A Review of Recent Progress. Liquids 2022, 2, 50–71.
7. Zuhail, K.P.; Humar, M.; Dhara, S. Effect of Phase Transitions on Liquid Crystal Colloids: A Short Review. Liq. Cryst. Rev. 2020, 8, 44–57.
8. Chattopadhyay, J.; Srivastava, R. Liquid Crystals with Nano/Micro Particles and Their Applications; CRC Press: Boca Raton, FL, USA, 2023.
9. Xia, Y.; Chen, Q.; Banin, U. Introduction: Anisotropic Nanomaterials. Chem. Rev. 2023, 123, 3325–3328.
10. Kato, T.; Uchida, J.; Ichikawa, T.; Sakamoto, T. Functional Liquid Crystals towards the next Generation of Materials. Angew. Chemie Int. Ed. 2018, 57, 4355–4371.
11. Gudimalla, A.; Lavrič, M.; Trček, M.; Harkai, S.; Rožič, B.; Cordoyiannis, G.; Thomas, S.; Pal, K.; Kutnjak, Z.; Kralj, S. Nanoparticle-Stabilized Lattices of Topological Defects in Liquid Crystals. Int. J. Thermophys. 2020, 41, 51.
12. Tschierske, C. Amphotropic Liquid Crystals. Curr. Opin. Colloid Interface Sci. 2002, 7, 355–370.
13. Awasthi, L.S.; Awasthi, K.S. General Observation about Liquid Crystals: A Review. Int. J. Eng. Res. Manag. Technol. 2015, 2, 1–20.
14. Shanker, G.; Paul, B.; Ganjiwale, A. Amino Acid and Peptide-Based Liquid Crystals: An Overview. Curr. Org. Synth. 2021, 18, 333–351.
15. Lisetski, L.N.; Vashchenko, O.V.; Kasian, N.A.; Sviechnikova, L.V. Lyotropic Liquid Crystal Phases of Phospholipids as Model Tools in Molecular Biophysics and Pharmacology. In Soft Matter Systems for Biomedical Applications; Bulavin, L., Lebovka, N., Eds.; Springer: Cham, Switzerland, 2022; pp. 85–111.
16. Shimizu, Y.; Takeuchi, H.; Takeuchi, R.; Ichikawa, T. Amphotropic Liquid-Crystalline Behaviour of Glycolipids in Amino Acid Ionic Liquids. Liq. Cryst. 2019, 46, 1298–1306.
17. Shahinpoor, M. Review of Liquid Crystal Elastomers. In Fundamentals of Smart Materials; Shahinpoor, M., Ed.; Royal Society of Chemistry: London, UK, 2020; pp. 243–253.
18. Ula, S.W.; Traugutt, N.A.; Volpe, R.H.; Patel, R.R.; Yu, K.; Yakacki, C.M. Liquid Crystal Elastomers: An Introduction and Review of Emerging Technologies. Liq. Cryst. Rev. 2018, 6, 78–107.
19. Rastogi, P.; Njuguna, J.; Kandasubramanian, B. Exploration of Elastomeric and Polymeric Liquid Crystals with Photothermal Actuation: A Review. Eur. Polym. J. 2019, 121, 109287.
20. Ruan, K.; Zhong, X.; Shi, X.; Dang, J.; Gu, J. Liquid Crystal Epoxy Resins with High Intrinsic Thermal Conductivities and Their Composites: A Mini-Review. Mater. Today Phys. 2021, 20,

100456.

21. Wen, Z.; Yang, K.; Raquez, J.-M. A Review on Liquid Crystal Polymers in Free-Standing Reversible Shape Memory Materials. Molecules 2020, 25, 1241.
22. Dierking, I. Polymer—Modified Liquid Crystals; Royal Society of Chemistry: London, UK, 2019.
23. Yuvaraj, A.R.; Lee, W.; Kumar, S. Unconventional Liquid Crystals: Chemical Aspects. In Unconventional Liquid Crystals and Their Applications; Lee, W., Kumar, S., Eds.; Walter de Gruyter GmbH & Co KG: Berlin, Germany, 2021; pp. 109–151.
24. Bisoyi, H.K.; Li, Q. Liquid Crystals: Versatile Self-Organized Smart Soft Materials. Chem. Rev. 2021, 122, 4887–4926.
25. Goossens, K.; Lava, K.; Bielawski, C.W.; Binnemans, K. Ionic Liquid Crystals: Versatile Materials. Chem. Rev. 2016, 116, 4643–4807.
26. Vill, V.; Sajus, H.; Thiemann, T. LiqCryst 2.1: Database and Scientific Tool. In Liquid Crystals: Physics, Technology, and Applications; Rutkowska, J., Klosowicz, S.J., Zielinski, J., Zmija, J., Eds.; SPIE: Bellingham, WA, USA, 1998; Volume 3318, pp. 160–162.
27. Goodby, J.W.; Collings, P.J.; Kato, T.; Tschierske, C.; Gleeson, H.; Raynes, P.; Vill, V. Handbook of Liquid Crystals, 8 Volume Set; John Wiley & Sons: Hoboken, NJ, USA, 2014; Volume 1.
28. Khoo, I.-C. Liquid Crystals; John Wiley & Sons: Hoboken, NJ, USA, 2022.
29. DiLisi, G.A.; DeLuca, J.J. An Introduction to Liquid Crystals; Morgan & Claypool Publishers: San Rafael, CA, USA, 2019.
30. Oswald, P.; Pieranski, P. Liquid Crystals: Concepts and Physical Properties Illustrated by Experiments; CRC Press: Boca Raton, FL, USA; Taylor & Francis Group: Hoboken, NJ, USA, 2018.
31. Kasian, N.A.; Lisetski, L.N.; Gvozdovskyy, I.A. Twist-Bend Nematics and Heliconical Cholesterics: A Physico-Chemical Analysis of Phase Transitions and Related Specific Properties. Liq. Cryst. 2022, 49, 142–152.
32. Nazarenko, K.G.; Kasian, N.A.; Minenko, S.S.; Samoilov, O.M.; Nazarenko, V.G.; Lisetski, L.N.; Gvozdovskyy, I.A. Chiral Ferronematic Liquid Crystals: A Physico-Chemical Analysis of Phase Transitions and Induced Helical Twisting. Liq. Cryst. 2023, 50, 98–109.
33. Hamley, I.W. Introduction to Soft Matter: Synthetic and Biological Self-Assembling Materials; John Wiley & Sons: Chichester, UK, 2007.
34. Marques, E.; Silva, B. Surfactants, Phase Behavior. In Encyclopedia of Colloid and Interface Science; Tadros, T., Ed.; Springer: Berlin/Heidelberg, Germany, 2013; pp. 1290–1333.

35. Wang, X.; Zhang, Y.; Gui, S.; Huang, J.; Cao, J.; Li, Z.; Li, Q.; Chu, X. Characterization of Lipid-Based Lyotropic Liquid Crystal and Effects of Guest Molecules on Its Microstructure: A Systematic Review. AAPS PharmSciTech 2018, 19, 2023–2040.
36. Kim, D.-H.; Jahn, A.; Cho, S.-J.; Kim, J.S.; Ki, M.-H.; Kim, D.-D. Lyotropic Liquid Crystal Systems in Drug Delivery: A Review. J. Pharm. Investig. 2015, 45, 1–11.
37. Dierking, I.; Martins Figueiredo Neto, A. Novel Trends in Lyotropic Liquid Crystals. Crystals 2020, 10, 604.
38. Hamade, F.; Amit, S.K.; Woods, M.B.; Davis, V.A. The Effects of Size and Shape Dispersity on the Phase Behavior of Nanomesogen Lyotropic Liquid Crystals. Crystals 2020, 10, 715.

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