Bent-Core Liquid Crystals: Structures and Mesomorphic Properties

Dan Scutaru, Irina Carlescu, Elena-Raluca Bulai (Cioanca), Catalina Ionica Ciobanu, Gabriela Lisa and Nicolae Hurduc

Abstract

Bent-core (BC) molecules became an attractive liquid crystal class due to their potential use in smart displays and photonic devices. In contrast to calamitic mesogens, bent-shaped mesogens are self-organized superstructures with remarkable properties, given the presence of polar order in mesophases, although the molecules themselves are not chiral. A particular interest represents the biaxial nematic liquid crystal materials that are used in display technology and allow a faster switching response, compared to calamitic liquid crystals, with considerably reduced costs. This chapter briefly reviews the bent-core liquid crystals with three different core units in the structure: (1) 2,5-disubstituted oxadiazole, (2) 1,3-disubstituted benzene, and (3) 2,7-disubstituted naphthalene. To the central bent units (BUs) containing reactive functional groups of phenolic or aminic type, various mesogenic groups are symmetrically or asymmetrically connected, via esterification or condensation reactions. The obtained compounds showed biaxial nematic and/or smectic mesophases with high transition temperatures in the case of oxadiazole derivatives or cholesteric and banana-type mesophases with lower transition temperatures in the case of benzene and naphthalene derivatives.

Keywords: liquid crystals, bent-core molecules, resorcinol, naphthalene, oxadiazole, azomesogens, biaxial, nematic, smectic, cholesteric

1. Introduction

Liquid crystal displays (LCDs) are omnipresent in modern world, representing probably the most prevalent, developed, and profitable technology of thermotropic liquid crystals [1, 2]. This application is based on their sensitivity to external electric and magnetic fields, when molecules align fast and at low voltages. This property was the basis for their use in other interesting applications, especially as sensors. Because of their fluid nature at a certain temperature, liquid crystals (LCs) are very easy to process in thin films, along with maintaining optical properties characteristic to crystalline materials, as the ability to rotate the polarized light plane (birefringence).

The discovery of portable devices and the introduction of easily used tactile displays resulted in a new change of direction in LCD technologies. Present researches focus on synthesis, characterization, and analysis of new mesogenic structures with high dielectric anisotropy ($\Delta \varepsilon$) (for inducing the decrease of voltage), low
rotational viscosity ($\gamma_1$) (allowing fast switching), birefringence ($\Delta n$) suitable to accurate display design, good solubility, and a broad nematic phase domain [2].

The increasing interest for bent-core (BC) liquid crystals in the past two decades is due to their ability to provide potential devices with fast switching response [3–7]. Therefore, the main purpose was to analyze the relation between biaxial molecular structures and electro-optical properties in this type of compound. From a technical point of view, the main objective is to look for the improvement of response time in order to reduce the motion effect in the case of large TVs and in displaying information in the case of tactile devices, respectively. The development of reliable functional materials that allow reduced chemical production cost was also considered [8].

Because of the bent shape that strongly deviates from linear symmetry axis, bent-core biaxial molecules are capable of special steric interactions, caused by the tendency to reduce the rotational disordering around the long axis. The bent-core molecules are preferentially packed into bent directions and parallelly aligned to each layer. Because of this imposed framing, each layer presents a spontaneous polarization ($P_s$), which is parallel or antiparallel to the molecular bent direction, while the molecules present the properties of switching without chirality, particularly useful for display screens. The existing bending angle between the arms permits the formation of unique self-organized systems with mesophases having no counterpart in conventional calamitic liquid crystals [4–7].

The special properties of biaxial molecules stimulated the researches in the field, so that a large number of banana-type compounds with various fragment structural combinations have been synthesized [9–17].

In banana-type compounds, eight different complex mesophase morphologies have been identified until now ($B_1$, $B_2$ ….. $B_8$), the distinction between phases being made on the basis of optical textures and characteristic differences in X-ray diffraction diagrams [18–22]. Literature data showed that the appearance of B-type mesophases depends mainly on an adequate combination between central unit and lateral rigid units. The general structure of BC molecules includes two symmetrical/asymmetrical mesogenic units of rod-like type connected to central units by linking groups (Figure 1). Usually, the angle between the arms depends mainly on the type of the connecting groups (around 120° and 140°) [23, 24].

Although remarkable progresses have been realized in thermal analysis, a precise correlation between BC chemical structures and their physical properties is still not possible, as for calamitic liquid crystal molecules. In many cases, molecules that present banana-type mesophases have a bent shape, but this does not always assure the mesophase appearance. Data show that for the appearance of B mesophases, two factors are necessary: (1) adequate distribution of charges along the arms [25] and (2) adequate bending angle [24].
The properties of biaxial liquid crystals can be influenced by the substituents of central nucleus, lateral arms, and terminal units. The central aromatic core generally consists of naphthalene, benzene, and heterocyclic units. A considerable influence may have the linking groups used for connecting the chemical structures. The most used connecting groups are of ester, azomethine, azo, stilbene, thiocarbonyl, or acryloyloxy type [26, 27]. The withdrawing or donating electronic groups may strongly affect the electronic density, the molecular flexibility, and the partial polarity of the molecule [25, 28]. The most interesting banana-type mesogenic compounds which presented switchable mesophase have been the ones containing azomethine groups. However, this linking group is thermally unstable in the presence of acidity and metallic surfaces, and some Schiff bases decomposing around 150°C, while others are stable up to 200°C.

Bent-core molecules containing azo linkages present remarkable properties because of the association of the photosensitive nature of azobenzene derivatives with ferroelectric liquid crystalline properties of BC compounds [13, 16, 29]. Although the first bent-core azo liquid crystalline compound was prepared by Vorländer in 1929, the pioneering work has been done by Prasad et al. who synthesized compounds containing aromatic rings and azo groups and presenting smectic phases [30]. Because of trans-cis photochemical isomerization of the azobenzene moiety, configurational modifications appear with significant changes on physical properties targeting dipole moment, refractive index, or viscosity [13].

The lateral substitution has a strong impact on liquid crystalline state or mesophase stability, respectively [31, 32]. The packing of molecules may be affected by size, polarity, and substitution position. The liquid crystalline properties may completely disappear after the introduction of bulky lateral substituents. Sometimes, interesting modifications have been observed in the switching behavior after the introduction of small polar substituents [9, 31, 33–35].

Hence, the study of biaxial LC based on bent-core units represents a very actual subject not only from a theoretical point of view but also for designing materials with special properties [36, 37]. The existence of a stable biaxial nematic mesophase can lead to a whole class of devices based on liquid crystals able to considerably improve the switching properties or behave as optical compensation films [38].

This chapter proposes to describe the relationship between the structure and supramolecular ordering properties of symmetrical and asymmetrical bent-core liquid crystals synthetized by our research group. In order to keep this chapter within a certain length, the detailed study on synthesis and complete characterization of compounds is not included here and may be found in the original papers [39–53]. In the following sections, the transition temperature (°C) and the type of mesophase for each compound are given below its chemical structure, while transitions in square brackets refer to monotropic phase. The phase behavior will be discussed in the text, where B stands for banana phase, Cr for crystal, LC for liquid crystal, Iso for isotropic phase, N for nematic phase, Sm for smectic phase, Ch for cholesteric phase, and d for decomposition process.

2. Relationship between structure and liquid crystalline properties

The mesomorphic behavior of bent-core compounds synthetized in our group was described through a systematic study that reviewed the nature of central bent core; the position, size, and the role of lateral substitution in the central unit; the symmetry or non-symmetry of rigid calamitic wings; the length, polarity, and micro-segregation of the terminal flexible chains; and the presence of the cholesteric moiety. The influence of the structure of calamitic wings was also considered,
regarding the number of aromatic rings and the nature of linking groups that contribute through polarity, orientation, and flexibility.

According to their core, banana-shaped compounds were divided into three categories: (1) 2,5-disubstituted oxadiazole; (2) 1,3-disubstituted benzene; and (3) 2,7-disubstituted naphthalene.

2.1 Bent-core compounds based on oxadiazole core

Among heterocyclic liquid crystals, the central unit in 2,5-disubstituted-[1,3,4]oxadiazoles assures the optimum geometry for bent-shaped molecules. Generally, the bending angle determined by the presence of 2,5-disubstituted oxadiazole central unit is between 134 and 140°, larger than the typical value of 120° in 1,3-disubstituted benzene unit. Moreover, the presence of three polarizable heteroatoms causes a high dipole moment that affects phase transition temperatures and mesophase types. Therefore, the presence of bent-shape and dipolar nature of the oxadiazole core together makes these compounds very attractive for applications.

When the central unit is symmetrically substituted with two azobenzene units with alkanoyloxy flexible chain ends (compound 1), the mesomorphic properties vary with the number of carbon atoms.

Thus, for compounds of type 1 containing a smaller number of carbon atoms \((n = 4, 5)\), the mesophase is of nematic type with characteristic Schlieren texture. The change occurs for \(n = 6\), when the compound shows the lowest liquid crystal-line domain on heating, but dendritic-like texture on cooling, characteristic of \(B_1\) phase \([39]\). Further increase of carbon atoms results in progressive growth of the mesomorphic intervals, with \(B_4\) chirally separated domains, evidenced on cooling by dark and bright domains after rotation of one of the polarizers clockwise or anticlockwise from the crossed \((90°)\) position (Figure 2). On the other hand, the

\[\begin{align*}
1a, & n = 4, \text{Cr} 264 \text{N} 289 \text{Iso} \\
1b, & n = 5, \text{Cr} 256 \text{N} 284 \text{Iso} \\
1c, & n = 6, \text{Cr} 253 B_1 276 \text{Iso} \\
1d, & n = 7, \text{Cr} 249 B_2 273 \text{Iso} \\
1e, & n = 8, \text{Cr} 244 B_3 274 \text{Iso} \\
1f, & n = 9, \text{Cr} 244 B_4 275 \text{Iso} \\
1g, & n = 17 \text{ (cis)}, \text{Cr (B_1 210) 212 Iso}
\end{align*}\]

Figure 2.
Textures of \(B_4\) chiral domains’ phase of compound 1f at \(T = 175°C\) between slightly de-crossed polarizers from \(90°\) by about \(+/−5°\).
introduction of elaidic or oleic units (n = 17, cis, trans) on the terminal chain destabi-
ligizes (1g, monotropic) or suppress the mesophase.

Compounds of type 2, containing one more benzene ring in each side arm and
azomethine linking groups, exhibited a rich polymorphism, induced by repulsion
effects between the hydrogen atom of the azomethine group and the aromatic
system. The compounds presented smectic phase and/or characteristic nematic
droplets or Schlieren textures on broad domains (between 89 and 169°C), which
go up to high transition temperatures (higher than 330°C), with decomposition
before isotropization [40]. Thermal degradation studies revealed that the com-
ponds with even methylene groups show a lower stability compared to those with
odd ones [41].

Replacing the acyloxy terminal chain with an alkoxy one in compounds of type
3 results in decreasing the isotropization temperatures alongside with mesomorphic
domains. For this class, the compound with 10 carbon atoms in the aliphatic chain
showed the highest stability of mesophase. All compounds presented similar poly-
morphism to that of 2, analogous with nematic droplet phases or Schlieren textures,
characteristic of bent-core compounds (Figure 3).

Figure 3.
Optical micrographs of mesophases: (a) 3a, 285°C, heating; (b) 3e, 205°C, cooling.
The asymmetric hockey-stick derivatives of type 4 showed the widest mesophase domains (between 123 and 198°C), compared to compounds 1–3 [42]. The mesophase behavior was explained by the strong dipolar interactions between molecules, determined by the asymmetric substitution of the oxadiazole core with a shorter side arm, where the molecules bend is not emphasized as for classical bent-core compounds.

As for previous compounds, the stability of mesophases follows the odd-even effect, because of changing the ability to order into mesophase. Thus, the increase of aliphatic chain to 18 carbon atoms induces changes in supramolecular ordering, which leads to the narrowest mesophase range. All the compounds showed mesophases ordered into nematic phases of ribbon type or with characteristic Schlieren textures. The last compound of the series (n = 18) presented smectic textures.

2.2 Bent-core compounds based on benzene core

1,3-Disubstituted benzene derivatives represent the first class of synthesized bent-core liquid crystals, with the largest number of reported compounds [22]. Our studies are based on two types of benzene core: resorcinol and 1,3-diaminobenzene.

2.2.1 Resorcinol central unit

The symmetric disubstitution of resorcinol with dimeric azomesogens or imino-azo mesogens with terminal flexible chains results in mesomorphic compounds evidencing Sm or B phases with relatively stable mesophase domains. In the case of compound 5a, SmB dendritic textures were identified from isotropic melt that changed into a B1 mosaic one at lower temperature [43].

Increasing the alkyl chain to 7 (compound 5b) and 8 (compound 5c) carbon atoms stabilized the mesophase but only on a relatively narrow interval of
temperature. Further increase in the length of the chain completely destabilized the liquid crystalline behavior due to the disorder induced by the flexible unit in relation to the rigid one, so compounds 5d and 5e are non mesomorphic [43].

Compounds 6a–e show predominantly smectic phases with characteristic fan-shaped textures [44]. Oily streak texture was identified in the case of compound 6e on first heating, that poorly developed into fan-like textures with striations across individual fans from the isotropic melt (Figure 4a, b). The mesophase domains are better stabilized for the first (6a) and the last compounds (6e) of this series. The insertion of polar acyloxy linkage between terminal chain and aromatic ring increases the physical interactions between molecules, with consequences on the isotropization temperatures together with increases of the mesophase domains at around 30°C (compound 7a) [44].

As for previous compounds of type 6, predominately smectic phases were identified on heating and nematic and smectic phases on cooling, respectively. However, banana B7 phase has been identified in the case of compound 7b on cooling from the isotropic melt, with characteristic spiral and circular domains and equidistant line pattern (Figure 5a). Thin filament texture in a spiral fashion network, which preceded smectic phase, was visible on heating for compounds 7d and 7e (Figure 5b).

![Figure 4](image)

**Figure 4.**
Optical micrographs of mesophases of compound 6e, (a) 195°C, heating; (b) 170°C, cooling.
The asymmetric disubstitution of resorcinol resulted in bent-core compounds containing only one typical mesogenic arm, formed by two aromatic rings connected via ester or azo linking groups and containing alkyloxy terminal flexible chains, while the other arm contained only a benzyl unit [45]. In this case, the liquid crystalline behavior depends on the type of the linkage between the aromatic rings in the long arm. Hence, the presence of azo linkage allows the formation only of monotropic phases (compounds 8a–e).

The mesophase appearance was identified mainly as mosaic textures of the banana B\textsubscript{1} phase that precedes the focal conic domains from isotropic melt on cooling (Figure 6a) for compounds 8a–8d, while the increase of the terminal chain to 10 carbon atoms favors the formation of the nematic phase.

In contrast to compounds 8a–8e, the presence of the carbonyloxy linkage in compounds 9a–9e stabilizes the mesophase mostly into enantiotropic behavior, with typical cylindrical focal conic domains that succeed the nematic phase on cooling. In the case of compound 9d, the coexistence of a fingerprint-like texture and a focal pseudo-isotropic region (black) was observed on cooling (Figure 6b). It was noted that the liquid crystalline behavior and transition temperatures follow the odd–even effect in accordance with the number of carbon atoms in the terminal alkyl chain, the most stable mesophases being evidenced by compounds with an even number of carbon atoms.
When benzyl unit in compounds 8 and 9 is replaced by a cholesteryl moiety linked by a pentamethylene flexible spacer to resorcinol (compounds 10 and 11), the liquid crystalline behavior changed significantly [46].

When benzyl unit in compounds 8 and 9 is replaced by a cholesteryl moiety linked by a pentamethylene flexible spacer to resorcinol (compounds 10 and 11), the liquid crystalline behavior changed significantly [46].

In the case of compounds 10a–10f, containing azo linkage between the aromatic cycles, only smectic-type textures were observed, the most stable interval of the mesophase being observed for compound 10a, with the shorter flexible terminal chain (n = 6). Because of strong polar interactions, all compounds presented high viscosity and crystallized very slowly below room temperature. Compared with compounds 10a–10e, compounds 11a–11e presented a rich polymorphism on heating with crystalline-crystalline or liquid crystalline-liquid crystalline transitions, on a narrow range of mesophases. However, neither characteristic cholesteric textures were observed as was the case for compounds with azo linkage in the structure; only smectic phases have been observed (Figure 7a,b). As for previous compounds 10a–10e, on cooling, compounds 11a–11e presented mesophases much below room temperature.
Compounds 12 and 13 were obtained when the flexible spacer between resorcinol and cholesteryl unit in compounds 10 and 11 was changed to a succinate one [47].

Compounds of type 12 presented wider mesophase domains on heating and cooling (compared with compounds of type 10), suggesting better interactions when the flexible chain inside one arm is shorter. While compounds 12a–e showed enantiotropic behavior with smectic-type textures, when switching the azo unit with an ester the mesophases are destabilized, with compounds 13a–e presenting only monotropic behavior. Whereas the first two compounds, 13a and 13b, showed smectic phases, the next homologous compound presented cholesteric phases.

2.2.2. 1,3-Diaminobenzene central core

Symmetric derivatives 14a–14d presented focal-conic and fan-shaped textures, which are characteristic of the banana B_6 phase (Figure 8) (compound 14e (n = 10) is non mesomorphic) [48]. The mesophase stability ranges decrease with the number of the carbon atoms in the alkyl chain, and the variation of transition temperature follows the odd/even effect, derivatives with an even number of carbon atoms present a larger domain of mesophase.

Figure 7. Optical micrographs of mesophases: (a) 10d, 115°C, heating and (b) 11c, 71°C, cooling.
The liquid crystalline properties of asymmetric bent-core derivatives 15 and 16 depend on the nature of the X substituent [49]. Thus, for X = -H, compounds 15a–15e showed an enantiotropic behavior with fan-shaped texture characteristic of the banana B6 phase while replacement of hydrogen atom with ▬Br decreased the mesophase stability, so compounds 16a–16d presented only monotropic behavior with narrow intervals of mesophases.
Compounds of type 17 and 18 were obtained by condensing 4-methylbenzene-1,3-diamine with 4′-alkyloxy-4-formylazobenzene and 4′-acyloxy-4-formylazobenzene, respectively [50].

Compounds with alkyloxy terminal flexible chain (compounds 17a–17f) evidenced nematic phases on heating and smectic textures on cooling. Introduction of an acyl group as terminal chain (compounds 18a–18f) has as result the slight increase of the transition temperatures but a decrease of mesophase stability, such that only compounds 18c–18f showed mesomorphic behavior.

However, the optical microscope observations revealed focal-conic or fan-like textures for compounds 18c–18f on cooling, characteristic of the banana B2 phase, with striations across individual fans which on further cooling transform into mosaic textures (Figure 8).

2.3. Bent-core compounds based on 2,7-dihydroxynaphtalene core

The presence of a naphthalene unit in banana-shaped compounds is characterized by increased temperature transitions, compared to previous compounds with a benzene central core. Hence, the nematic mesophase domains of compounds 19a–19e are situated between 175 and 214°C. The nematic phases were identified by characteristic Schlieren textures and nematic droplets or ribbon-like textures [51].

The symmetric disubstitution of compounds of type 19 gave compounds of type 20, which are non mesomorphic [51].
The asymmetric disubstituted compounds 21 and 22 that differ only by X substituent showed similar monotropic behavior, mainly with nematic textures [52].

If compared with previous naphthalene derivatives, transition temperatures were relatively low, something higher in brominated derivatives 22a–22e. While the mesophase ranges on cooling for compounds 21a–21e are larger, the mesophase domains of derivatives 22a–22e are much narrower, proving the destabilizing effect of the bulky bromine atom.

Anyway, compound 22e showed enantiotropic behavior, meaning that a length of 10 carbon atoms on the alkyl terminal chain compensated the negative effect of bromine and stabilized the liquid crystalline character. Only the last two compounds of this series showed fan-shaped textures of banana B6 growing from the isotropic melt on cooling.

The introduction of benzyl unit to compounds 19a–19e led to compounds 23a–23e, where only the last three compounds of the series showed enantiotropic behavior [53]. It was noted that though the melting and isotropization transition temperatures were lower, considering the hydrogen bonding interaction in compounds 19a–19e, but at the same time, the mesophase domains were larger, up to 35°C in compound 23e.
Comparing this series with compounds 8a–8e, where the central core derived from resorcinol, the favorable effect of naphthalene as central core was observed, since compounds 8a–8e showed only a monotropic behavior.

Changing the azo linkage in compounds 23a–23e with ester results in compounds 24a–24e, where only the first three homologous compounds, with shorter alkyl chains, presented enantiotropic behavior [53]. The presence of ester linkage increases the transition temperatures but decreases the mesophase range, if one considers compound 24c (21°C), compared with 23c (30°C).

3. Conclusions

We have presented here, in brief, a part of the work carried out by our group over a period of 16 years, from the standpoint of relationship between the structure and mesomorphic properties on some banana-shaped compounds. Our purpose was to investigate a variety of new compounds in order to design bent-shaped liquid crystals with large mesophase intervals at low transition temperatures, which might expand the field of electro-optical applications. It was found that the mesomorphic behavior depends upon the type of the bent unit, the number of aromatic units in the calamitic substituents, the nature of the linkages, the lateral substitution, and the length as well as the type of the terminal flexible chains. Hence, biaxial nematic, smectic, and cholesteric banana phases as well as less conventional mesophases were identified. The use of resorcinol as central bent unit had proved to be very useful in inducing various mesophases, with some transitions being evidenced even at low temperatures. Derivatives with the smallest length of terminal chains (especially n = 6) presented the widest mesophase interval. In terms of symmetrical derivatives, while the presence only of two aromatic cycles on each arm was not enough to stabilize or to induce the mesophase, the introduction of a third aromatic cycle has substantially improved the liquid crystalline properties. In asymmetrical derivatives, the presence of ester and azo linkages between aromatic rings influenced better the mesophase behavior or stability, compared with the situation when only ester linkages were present, except for derivatives with benzyl unit on the shorter arm. Moreover, the introduction of a cholesteryl hexanoate moiety on the second asymmetric arm led to mesophase transitions much below room temperature. In 1,3-diaminobenzene derivatives, the presence of bromine atom as lateral substituent on a calamitic arm destabilized or suppressed the mesophase. However, compared with resorcinol symmetrical derivatives with two aromatic cycles on each arm, just switching the places of ester and azo linkages between cycles had a better influence on liquid crystalline properties. Of the oxadiazole compounds, the hockey-stick derivatives showed the widest nematic ranges, particularly for the homologous compound with smallest number of carbon atoms in the terminal chain (n = 6). In symmetrical derivatives, the presence of three aromatic cycles on each arm and of acyloxy linkage on terminal chain induced better interactions and favorable packing, especially for compounds with higher number of carbon atoms in terminal flexible chain (n = 9–11), but increased too much the isotropization temperatures up to the beginning of the degradation processes. The presence of 2,7-disubstituted naphthalene as central core in bent-core compounds mainly destabilized the mesophases, compared with 1,3-disubstituted benzene derivatives.

Overall, considering the high impact of liquid crystal displays in everyday life and the multiple possibilities that bent-core compounds offer to vary the properties of materials, it is expected that the present study will contribute to future research directions, hopefully not only in fundamental or theoretical research but also in practical applications.
Conflict of interest

No potential conflict of interest was reported by the authors.

Author details

Dan Scutaru¹, Irina Carlescu*, Elena-Raluca Bulai (Cioanca)¹,², Catalina Ionica Ciobanu³, Gabriela Lisa¹ and Nicolae Hurduc¹

1 “Cristofor Simionescu” Faculty of Chemical Engineering and Environmental Protection, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania

2 “Stefan cel Mare” University of Suceava, Suceava, Romania

3 Research Department, Faculty of Chemistry, “Al. I. Cuza” University, Iasi, Romania

*Address all correspondence to: icarlescu@ch.tuiasi.ro

IntechOpen

© 2018 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Liquid Crystals

References

[1] Bremer M, Kirsch P, Klasen-Memmer M, Tarumi K. The TV in your pocket: Development of liquid-crystal materials for the new millennium. Angewandte Chemie (International Ed. in English). 2013;52(34):8880-8896. DOI: 10.1002/anie.201300903

[2] Kato T, Uchida J, Ichikawa T, Sakamoto T. Functional liquid crystals towards the next generation of materials. Angewandte Chemie (International Ed. in English). 2018;57(16):4355-4371. DOI: 10.1002/anie.201711163

[3] Acharya BR, Primak A, Kumar S. Biaxial nematic phase in bent-core thermotropic mesogen. Physical Review Letters. 2004;92(14):145506. DOI: 10.1103/PhysRevLett.92.145506

[4] Jakli A. Liquid crystals of the twenty-first century—nematic phase of bent-core molecules. Liquid Crystals. 2013;1(1):65-82. DOI: 10.1080/21680396.2013.803701

[5] Gleeson HF, Kaur S, Gortz V, Belaissaoui A, Cowling S, Goodby JW. The nematic phases of bent-core liquid crystals. ChemPhysChem. 2014;15(7):1251-1260. DOI: 10.1002/cphc.201400014

[6] Buka A, Eber N, Fodor-Csorba K, Jakli A, Salamon P. Physical properties of a bent-core nematic liquid crystal and its mixtures with calamitic molecules. Phase Transitions. 2015;85(10):872-887. DOI: 10.1080/01411594.2012.689834

[7] Khan RK, Turlapati S, Rao NVS, Ghosh S. Elastic and dielectric properties of ferroelectric nanoparticles/bent-core nematic liquid crystal blend. European Physical Journal E: Soft Matter and Biological Physics. 2017;40(9):75. DOI: 10.1140/epje/i2017-11564-x

[8] Barche J, Janietz S, Ahles M, Schmechel R, von Seggern H. Cross-linked liquid-crystalline materials—A possible strategy to ordered organic semiconductors. Chemistry of Materials. 2004;16(22):4286-4291. DOI: 10.1021/cm049352l

[9] Pelzl G, Diele S, Weissflog W. Banana-shaped compounds—A new field of liquid crystals. Advanced Materials. 1999;11(9):707-724. DOI: 10.1002/(SICI)1521-4095(199906)11:9<707::AID-ADMA707>3.3.CO;2-4

[10] Marx VM, Girgis H, Heiney PA, Hegmann T. Bent-core liquid crystal (LC) decorated gold nanoclusters: Synthesis, self-assembly, and effects in mixtures with bent-core LC hosts. Journal of Materials Chemistry. 2008;18(25):2983-2994. DOI: 10.1039/b802554a

[11] Etxebarria J, Ros MB. Bent-core liquid crystals in the route to functional materials. Journal of Materials Chemistry. 2008;18(25):2919-2926. DOI: 10.1039/b803507e

[12] Alaasar M, Prehm M, Poppe S, Tschierske C. Development of polar order by liquid-crystal self-assembly of weakly bent molecules. Chemistry – A European Journal. 2017;23(23):5541-5556. DOI: 10.1002/chem.201606035

[13] Alaasar M. Azobenzene-containing bent-core liquid crystals: An overview. Liquid Crystals. 2016;43(13-15):2208-2243. DOI: 10.1080/02678292.2016.1175676

[14] Alaasar M, Prehm M, Tschierske C. Mirror symmetry breaking in fluorinated bent-core mesogens. RSC Advances. 2016;6(86):82890-82899. DOI: 10.1039/c6ra18482k

[15] Kohout M, Alaasar M, Poryvai A, Novotna V, Poppe S, Tschierske C,
et al. Photosensitive bent-core liquid crystals based on methyl substituted 3-hydroxybenzoic acid. RSC Advances. 2017;7(57):35805-35813. DOI: 10.1039/c7ra05632j

[16] Srinivasa HT. New symmetric azobenzene molecules of varied central cores: Synthesis and characterisation for liquid crystalline properties. Liquid Crystals. 2017;44(9):1384-1393. DOI: 10.1080/02678292.2017.1280620

[17] Khan RK, Turlapati S, Begum N, Mohiuddin G, Rao NVS, Ghosh S. Impact of terminal polar substitution on elastic, electro-optic and dielectric properties of four-ring bent-core nematic liquid crystals. RSC Advances. 2018;8(21):11509-11516. DOI: 10.1039/c8ra00575c

[18] Niori T, Sekine T, Watanabe J, Furukawa T, Takezoe H. Distinct ferroelectric smectic liquid crystals consisting of banana shaped achiral molecules. Journal of Materials Chemistry. 1996;6(7):1231-1233. DOI: 10.1039/jm960601231

[19] Tschierske C, Dantlgraber G. From antiferroelectricity to ferroelectricity in smectic mesophases formed by bent-core molecules. Pramana. 2003;61(2):455-481. DOI: 10.1007/BF02708325

[20] Acharya BR, Primak A, Dingemans TJ, Samulski ET, Kumar S. The elusive thermotropic biaxial nematic phase in rigid bent-core molecules. Pramana. 2003;61(2):231-237. DOI: 10.1007/BF02708305

[21] Acharya BR, Primak A, Kumar S. Biaxial nematic phase in bent-core thermotropic mesogens. Physical Review Letters. 2004;92(14):145506. DOI: 10.1103/PhysRevLett.92.145506

[22] Kumar S, Gowda AN. The chemistry of bent-core molecules forming nematic liquid crystals. Liquid Crystals Reviews. 2015;3(2):99-145. DOI: 10.1080/21680396.2015.1061958

[23] Shen D, Diele S, Pelzl G, Wirth I, Tschierske C. Designing banana-shaped liquid crystals without Schiff's base units: m-terphenyls, 2,6-diphenylpyridines and V-shaped tolane derivatives. Journal of Materials Chemistry. 1999;9(3):661-672. DOI: 10.1039/a808275h

[24] Kang S, Saito Y, Watanabe N, Tokita M, Takanishi Y, Takezoe H, et al. Low-birefringent, chiral banana phase below calamitic nematic and/or smectic C phases in oxadiazole derivatives. The Journal of Physical Chemistry. B. 2006;110(11):5205-5214. DOI: 10.1021/jp057307a

[25] Bedel JP, Rouillon JC, Marcerou JP, Laguerre M, Nguyen HT, Achard MF. Influence of fluoro substituents on the mesophase behaviour of banana-shaped molecules. Journal of Materials Chemistry. 2002;12(8):2214-2220. DOI: 10.1039/b201467j

[26] Nguyen HT, Rouillon JC, Marcerou JP, Bedel JP, Barois P, Sarmento S. Mesomorphic and electro-optical properties of new achiral banana-shaped molecule. Molecular Crystals and Liquid Crystals. 1999;328:177-184. DOI: 10.1080/10587259908026057

[27] Sadasivak BK, Reddy AR, Pratibha R, Madhusudana NV. Biaxial smectic A liquid crystal in a pure compound. Chemical Communications. 2001;20:2140-2141. DOI: 10.1039/b106084h

[28] Bedel JP, Rouillon JC, Marcerou JP, Laguerre M, Nguyen HT, Achard MF. New switchable smectic phases in banana-shaped compounds. Liquid Crystals. 2001;28(9):1285-1292. DOI: 10.1080/02678290110039949

[29] Alaasar M, Prehm M, Tschierske C. New azobenzene containing
bent-core liquid crystals based on disubstituted resorcinol. Liquid Crystals. 2014;41(1):126-136. DOI: 10.1080/02678292.2013.840393

[30] Prasad V, Rao DSS, Prasad SK. A novel class of banana-shaped azo compounds exhibiting antiferroelectric switching behaviour. Liquid Crystals. 2001;28(4):643-646. DOI: 10.1080/02678290010020887

[31] Dunemann U, Schroder MW, Reddy RA, Pelzl G, Diele S, Weissflog W. The influence of lateral substituents on the mesophase behaviour of banana-shaped mesogens. Part II. Journal of Materials Chemistry. 2005;15(37):4051-4061. DOI: 10.1039/b507458d

[32] Weissflog W, Baumeister U. Laterally aryl-substituted bent-core mesogens. Liquid Crystals. 2013;40(7):959-967. DOI: 10.1080/02678292.2013.786797

[33] Jakli A, Lischka C, Weissflog W, Pezl G, Rauch S, Heppke G. Structural transitions of smectic phases formed by achiral bent-core molecules. Ferroelectrics. 2000;243(1-4):239-+. DOI: 10.1080/00150190008008025

[34] Ros MB, Serrano JL, de la Fuente MR, Focia CL. Banana-shaped liquid crystals: A new field to explore. Journal of Materials Chemistry. 2005;15(48):5093-5098. DOI: 10.1039/b504384k

[35] Findeisen-Tandel S, Weissflog W, Baumeister U, Pelzl G, Murthy HNS, Yelamagadd CV. Laterally substituted symmetric and nonsymmetric salicylideneimine-based bent-core mesogens. Beilstein Journal of Organic Chemistry. 2012;8:129-154. DOI: 10.3762/bjoc.8.15

[36] Fleischmann EK, Zentel R. Liquid-crystalline ordering as a concept in materials science: From semiconductors to stimuli-responsive devices.

[37] Tschierske C. Development of structural complexity by liquid-crystal self-assembly. Angewandte Chemie, International Edition. 2013;52(34):8828-8878. DOI: 10.1002/anie.201300872

[38] Prasad V, Kang SW, Suresh KA, Joshi L, Wang QB, Kumar S. Thermotropic uniaxial and biaxial nematic and smectic phases in bent-core mesogens. Journal of the American Chemical Society. 2005;127(49):17224-17227. DOI: 10.1021/ja052769n

[39] Bulai ER, Carlescu I, Scutaru D. Synthesis and characterisation of liquid crystalline compounds based on symmetric 1, 3, 4 oxadiazole core. Revista de Chimie. 2015;66(4):439-443

[40] Cioanca ER, Carlescu I, Wilson D, Scutaru D. Liquid crystalline Schiff bases containing a 2, 5-(p-aminophenyl)-[1, 3, 4]oxadiazole bent core. Revista de Chimie. 2010;61(12):1158-1163

[41] Lisa G, Cioanca ER, Tudorachi N, Carlescu I, Scutaru D. Thermal degradation of some [1, 3, 4]oxadiazole derivatives with liquid crystalline properties. Thermochimica Acta. 2011;524(1-2):179-185. DOI: 10.1016/j.tca.2011.07.01

[42] Cioanca ER, Epure EL, Carlescu I, Lisa G, Wilson D, Hurduc N, et al. Hockey stick liquid crystals based on a 2, 5-asymmetric disubstituted [1, 3, 4] oxadiazole core. Molecular Crystals and Liquid Crystals. 2011;537:51-63. DOI: 10.1080/15421406.2011.556444

[43] Ciobanu CI, Drochioiu G, Carlescu I, Lisa G, Antoci V, Vasilache V, et al. Thermal behaviour of some bent-core resorcinol derivatives with azo-type spacers and variable flexible...
Bent-Core Liquid Crystals: Structures and Mesomorphic Properties
DOI: http://dx.doi.org/10.5772/intechopen.81704

[44] Ciobanu CI, Carlescu I, Lisa G, Scutaru D. Symmetric bent-core liquid crystals of some Schiff bases containing azo linkage. Croatica Chemica Acta. 2014;87(1):7-16. DOI: 10.5562/cca2150

[45] Simion A, Carlescu I, Lisa G, Scutaru D. Unsymmetrical bent-core liquid crystals based on resorcinol core. Revista de Chimie. 2016;67(3):446-450

[46] Huzum CC, Carlescu I, Lisa G, Scutaru D. New cholesteryl containing bent core liquid crystals. Journal of the Serbian Chemical Society. 2013;78(5):669-680. DOI: 10.2298/JSC120810114H

[47] Huzum CC, Carlescu I, Lisa G, Scutaru D. Nonsymmetric liquid crystalline cholesteric dimers derived from resorcinol. Revista de Chimie. 2013;64(1):60-67

[48] Iuganu D, Carlescu I, Lisa G, Scutaru D. Symmetric bent-core liquid crystals based on 1, 3-bis-(4′-hydroxyphenylazo) benzene core. Revista de Chimie. 2012;63(5):501-506

[49] Iuganu D, Carlescu I, Lisa G, Scutaru D. Asymmetric bent-core liquid crystals based on 1, 3-bis-(4′-hydroxyphenylazo) benzene central core. Studia Universitatis Babes-Bolyai Chimia. 2011;56(4):63-74

[50] Ciobanu C, Carlescu I, Lisa G, Scutaru D. Synthesis and mesomorphic properties of some bent-core Schiff bases containing azo linkage. Revista de Chimie. 2013;64(3):249-253

[51] Simion G, Carlescu I, Lisa G, Scutaru D. Synthesis and characterization of some liquid crystalline compounds based on a 2, 7-dihydroxynaphthalene core. Revista de Chimie. 2012;63(4):407-411

[52] Simion G, Carlescu I, Lisa G, Scutaru D. Asymmetric bent-core liquid crystals based on 2, 7-dihydroxynaphthalene core with an azo and esteric connecting groups. Studia Universitatis Babes-Bolyai Chimia. 2011;56(4):75-88

[53] Simion A, Huzum CC, Carlescu I, Lisa G, Balan M, Scutaru D. Unsymmetrical banana-shaped liquid crystalline compounds derived from 2, 7-dihydroxynaphtalen. Journal of the Serbian Chemical Society. 2015;80(5):673-683. DOI: 10.2298/JSC140725126S