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Cyclopentane as a Structural Fragment in Liquid Crystals

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The effect on the physico-chemical properties of introducing cyclopentane and cyclopentane based fragments into the molecular structure of liquid crystals is discussed and rationalized in terms of existent theories; a comparison is made with the corresponding derivatives containing other well-known fragments.

Keywords Cyclopentane; liquid crystals; physico-chemical properties

1. Introduction

In continuation of our study of the structure-property relationships in liquid crystals containing the saturated fragments (see for example, the previous publications [1–3]) we present here a review which examines in some detail the effect of the introduction cyclopentane and cyclopentane-based fragments into the molecular structure of liquid crystals on the appearance of the mesophases and their physico-chemical properties. When possible, the properties of the cyclopentane derivatives will be compared with those of the corresponding derivatives containing other well-known fragments.

2. Mesomorphic Properties

The phase transition temperatures of the cyclopentane derivatives and reference compounds are presented in Tables 1–8, where Cr, Sm, SmC^*_A, SmC^*_γ, SmC^*, SmC^*_a, SmC, SmB, SmA, N, Ch, and I denote the crystalline, smectic, chiral smectic C^*_A, C^*_γ, C^*, C^*_α, smectic C, B, A, nematic, cholesteric, and isotropic phases, respectively. Values given in parentheses refer to monotropic phase transitions.

If we refer to cyclopentane as a planar molecule, the internal C-C-C angles of the ring would be those of the regular pentagon (108°) and would differ a little from those of a regular tetrahedron (109.5°) or strain-free open chain hydrocarbons (112.7°) that bond angle deformation should contribute little to the overall strain energy [4]. Although the planar molecule would have considerable strain arising from the five perfectly eclipsed C-C bonds. We can point out two ways that cyclopentane can deform to relieve this strain whilst retaining some of its original symmetry. Thus, displacement of one carbon atom above or below the plane of

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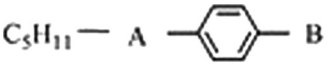
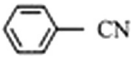
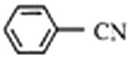
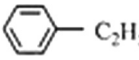
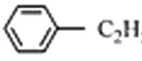
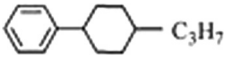
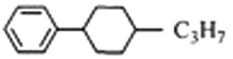
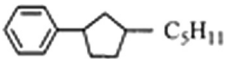
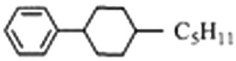
Table 1. Physico-chemical properties of liquid crystals:

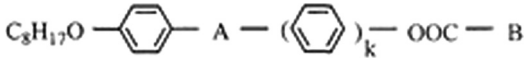


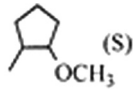
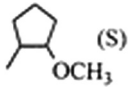
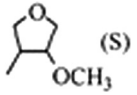
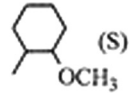
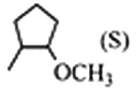
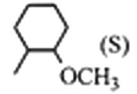
No.	A	B	Phase transitions, °C	Δε	v, mm^2s^{-1}	Ref.
1-1		CN	Cr < 20 I			[9]
1-2		CN	Cr 3 I N 55 I			[10]
1-3		 CN	Cr 50.5 N 61 I	10.1[a]	62[b]	[9]
1-4		 CN	Cr 96 N 222 I	9.1[c]	90[d]	[9,11]
1-5		 C_2H_5	Cr 20 Sm 37.51			[9]
1-6		 C_2H_5	Cr 34 Sm 146 N 164 I			[11]
1-7		 C_3H_7	Cr 20 Sm 165.5 Sm 172 I			[9]
1-8		 C_3H_7	Cr 58 SmB 232 SmA 251 N 311 I			[12]
1-9		 C_5H_{11}	Cr 20 Sm 73 I			[9]
1-10		 C_5H_{11}	Cr 55 Sm 247 SmA 275 N 305 I			[12]

[a] $\tau = T_{meas}/T_{N\text{-}I} = 0.95$, T_{meas}, $T_{N\text{-}I}$, K.
[b] Extrapolated from 10 wt% solution in the mixture of cyanobiphenyls at 20°C.
[c] Extrapolated from 10 wt% solution in ZLI-1132 at $\tau = 0.95$.
[d] Extrapolated from 10 wt% solution in ZLI-1132 at 20°C.

the other four atoms gives the envelope form with a plane of symmetry, C_s. And displacement of two adjacent carbon atoms at equal distances on either side of the plane of the remaining three gives the half-chair form with a two-fold axis of symmetry, C_2 [4]. It has been shown that the planar barrier of cyclopentane is equal to 154 kJ/mol [5]. The movement of the molecule from the C_s to C_2 forms as the first phase angle varies is called a pseudorotation. In a pseudorotation, the atoms themselves do not rotate, but it is the phase of the puckering that rotates around the ring [4]. The pseudorotation in cyclopentane has been confirmed by many works [6–8]. It is believed that these structural features of cyclopentane are responsible for significantly lower clearing points (nematic-isotropic or smectic-isotropic liquid phase

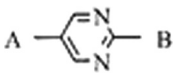
Table 2. Physico-chemical properties of liquid crystals:

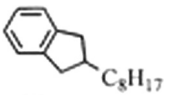
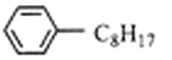
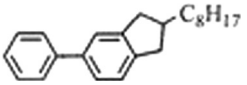
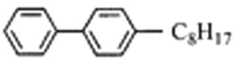
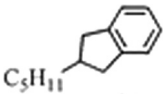
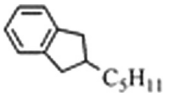
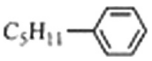
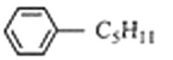
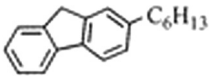
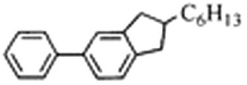
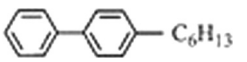


No.	A	k	B	Phase transitions, °C	$\lvert P_s^a \rvert$, nCcm^{-2}	Ref.
2-1	—	1	(R)  (S)	Cr 31.7 SmC* 34.2 Ch 41.4 I		[13]
2-2	—	1	(S)  (S)	Cr 34.5 SmC* 37.4 SmA 40 I		[13]
2-3	—	1	(R)  (S)	Cr 57.7 I		[13]
2-4	—	1	(R)  (S)	Cr 40.7 SmC* 42.6 Ch 71.8 I		[13]
2-5	COO	2	(R)  (S)	I 159.8 Ch 83 SmC* 22.4 Sm	143	[14]
2-6	COO	2	(R)  (S)	I 170.5 Ch 93.7 SmC* 22.2 Sm	160	[14]

[a] $T_{mean} = T_{SmC^*\text{-}Ch} - 10°C$.

Table 3. Mesomorphic properties of liquid crystals:

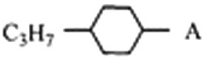


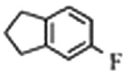
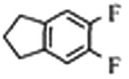
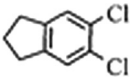
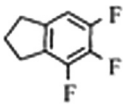
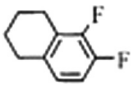
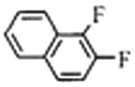
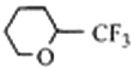
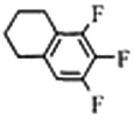
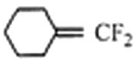
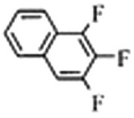
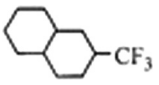
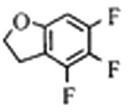
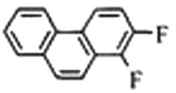
No.	A	B	Phase transitions, °C	Ref.
3-1	C_6H_{13}		Cr 47 N (43) I	[37]
3-2	C_6H_{13}		Cr 18 SmA 29.5 I	[38]
3-3	C_6H_{13}		Cr 74 N 139 I	[37]
3-4	C_6H_{13}		Cr 74.3 SmC 105.2 N 149.9 I	[39]
3-5			Cr 112 SmA 143 N 149 I	[37]
3-6			Cr 106 SmA 195 I	[40]
3-7	C_8H_{17}		Cr 76.9 SmA 140.9 N 144.2 I	[41]
3-8	C_8H_{17}		Cr 69 SmC 95 N 144 I	[37]
3-9	C_8H_{17}		Cr 65.6 SmC 98 SmA 141 N 156 I	[39]

transition temperatures) of the cylopentane derivatives in comparison with those of the corresponding trans-1,4-cyclohexylene derivatives (compounds **1-1–1-10**; **2-1, 2-2, 2-4–2-6**, Tables 1, 2).

As is evident from Table 1, increasing the number of cyclopentane rings introduced into the molecular core of liquid crystals further lowers the clearing points (compounds **1-7–1-10**). The introduction of oxygen into cyclopentane destroys its symmetry [8] and gives tetrahydrofuran which results in the disappearance of the mesophase of the tetrahydrofuran derivative **2-3** (Table 2). It has been demonstrated that the nematic-isotropic phase transition temperatures for trans-4-ethoxy-4′-cycloalkanecarbonyloxyazobenzenes monotonically rise from cyclopropane to cyclohexane and then, again monotonically, decline almost linearly to cycloundecane [15]. This drop in the clearing points can be explained in terms of reducing the intermolecular interactions caused by the significant rise of the size of the cycloalkanes from cyclohexane to cycloundecane [16]. Similar trends have been observed for other cyclopentane derivatives [17–33].

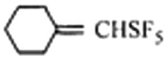
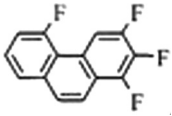
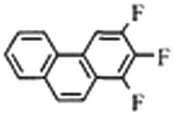
Table 4. Physico-chemical properties of liquid crystals:



No.	A	Phase transitions, °C	$\Delta\varepsilon^a$	Δn^a	ν^a, mm^2 s^{-1}	Ref.
4-1		Cr 75 I	3.6	0.080		[42]
4-2		Cr 75 I	10.9	0.084	12	[42]
4-3		Cr 148 I				[42]
4-4		Cr 52 I				[43]
4-5		Cr 36 N(35) I				[44]
4-6		Cr 42 N (33.3) I				[45]
4-7		Cr 59 I	8.8	0.061		[46]
4-8		Cr 51 N (−5) I Cr 52 I				[45] [44]
4-9		Cr 13 I			14	[47]
4-10		Cr 42 I				[45]
4-11		Cr 66 N (61.2) I	5.0	0.037	38	[48]
4-12		Cr 19 I	7.4	0.015		[49]
4-13		Cr 124 N 178.3 I	9.3	0.203		[50]

(*Continued*)

Table 4. Continued

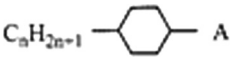
No.	A	Phase transitions, °C	$\Delta\varepsilon^a$	Δn^a	v^a, $mm^2\ s^{-1}$	Ref.
4-14		Cr 41 I	6.3	0.063		[51]
4-15		Cr 139 N (116.9) I	15.1	0.185		[50]
4-16		Cr 124 N 124.4 I	12.7	0.184		[50]

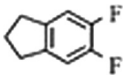
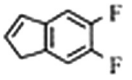
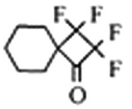
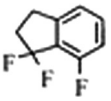
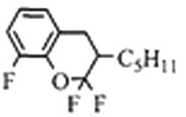
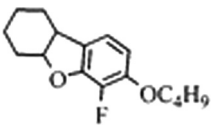
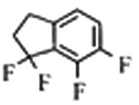
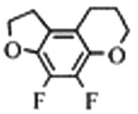
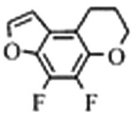
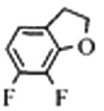
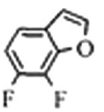
[a]Extrapolated from 10 wt% solution in ZLI-4792 at 20°C.

The fusion of cyclopentane and benzene gives indan which is puckered with the barrier to planarity of 160 kJ/mol [34–36]. It can be seen from Table 3 that the indan derivatives show more pronounced nematic behavior and higher (compounds **3-1, 3-2**) and lower clearing temperatures (compounds **3-3, 3-4**; **3-5, 3-6**; **3-8, 3-9**) in comparison with those of the corresponding 1,4-phenylene derivatives. The lateral fluoro or chloro substitution of indan can be used for adjusting the dielectric anisotropy of liquid crystals presented in Tables 4–7. It is evident from Tables 4, 5 that two-fragment indan derivatives are not mesomorphic (compounds **4-1**–**4-4, 5-1, 5-4**). The corresponding inden derivative shows the monotropic nematic phase (compounds **5-1, 5-2**). Also, the data presented in these tables reveal that decreasing the number of lateral fluorine atoms and/or increasing the number of the rings in the fused fragments usually gives more pronounced mesomorphic behavior of the compounds under consideration. Additionally, we would say that the introduction of the double carbon-carbon bonds into cyclohexane is not favorable for the creation of the mesophases (compounds **4-9, 4-14**), and an axial fluoro substitution gives more pronounced mesomorphic behavior than the lateral fluoro substitution of the cyclohexane derivatives (compounds **5-12, 5-13**), which can be explained by reducing the inter-molecular interactions in the latter case [16]. As expected, the introduction of fluorinated indans into the molecular core of three-fragment derivatives results in the formation of the mesophases, which exhibit the highest clearing points and melting temperatures in comparison with those of reference compounds (Tables 6, 7). Similar trends have been found for other indan derivatives [74–77].

Fluorene is the result of the fusion of cyclopentane and two benzene rings [78]. The CH_2 bridge makes this molecule planar [78] which is good for the mesomorphic properties, and simultaneously, the bridge both broadens the molecule and brings two benzene rings out of collinearity, the molecule being bent through an angle of 24° [78,79]. Tables 3, 8 demonstrate that the fluorene derivatives exhibit almost the same clearing temperatures compared with those of the corresponding indan derivatives (compounds **3-7, 3-8**). They show the decreased number of the mesophases and exhibit low (compounds **3-8, 3-9**) and higher clearing points (compounds **8-1**–**8-6**) in comparison with those of the corresponding biphenyl derivatives.

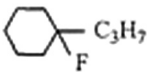
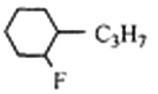
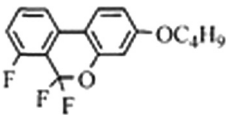
Table 5. Physico-chemical properties of liquid crystals:



No.	n	A	Phase transitions, °C	$\Delta\varepsilon^a$	Δn^a	ν^a, $mm^2\ s^{-1}$	Ref.
5-1	5		Cr 83 I	10.1	0.078		[42]
5-2	5		Cr 56 N (44.7) I	12.6	0.104	23	[42]
5-3	5		Cr 29 I	2.5	0.018		[52]
5-4	3		Cr 99 I	-7.1^b	0.086	136^c	[53]
5-5	3		Cr 25 I	-6.6^b	0.047		[54]
5-6	3		Cr 105 SmA 154 N 166 I	-5.6^b	0.114		[55]
5-7	3		Cr 85 I	-8.6^b	0.085	142^c	[53]
5-8	3		Cr 96 I	-7.0^b			[56]
5-9	3		Cr 89 I	-5.0^b			[56]
5-10	5		Cr 36 I	-4.9^b	0.015		[57]
5-11	5		Cr 37 I	-3.4^b	0.044		[57]

(*Continued*)

Table 5. Continued

No.	n	A	Phase transitions, °C	$\Delta\varepsilon^a$	Δn^a	ν^a, $mm^2\ s^{-1}$	Ref.
5-12	5		Cr 52 SmB 109 I	−2.1[b]	0.048		[47,58]
5-13	5		Cr 3 SmB 67 I	−0.9[b]	0.046		[59]
5-14	5		Cr 99 N 130.5 I	−16.7[b]	0.153		[60]

[a]Extrapolated from 10 wt% solution in ZLI-4792 at 20°C.
[b]Extrapolated from 10 wt% solution in ZLI-2857 at 20°C.
[c]Rotational viscosity γ_1 [mPas], extrapolated from 10 wt% solution in ZLI-4792 at 20°C.

The mesomophic properties of some other fluorene derivatives have been discussed in [26,27,85–100].

It can be proposed that the electronic and geometric structures of cyclopentane and cyclopentane-based fragments [4–8,34–36,38] play a very important role in the intra- and intermolecular interactions [101–103] which affect the packing of the molecules, that predominantly influences mesophase stability [101–104]. Anisotropic dispersion interactions, and consequently the anisotropy of polarizability, depending on the electron density distribution in the molecular fragments under consideration, also influence the packing, and hence the stability of the mesophases but play a secondary role compared to the steric factors [104]. Other molecular aspects such as the association [103] or dipole-dipole attraction in polar liquid crystalline derivatives, which can influence the packing of the molecules, also affect the stability of the mesophases [104].

3. Static Dielectric Properties

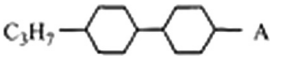
The relationship between the dielectric anisotropy $\Delta\varepsilon = \varepsilon_{||} - \varepsilon_{\perp}$, where $\varepsilon_{||}$ and $\varepsilon_{\perp}$ are, respectively, dielectric constants, that are parallel and perpendicular to the nematic director **n**; and molecular structure of liquid crystals is described by the theory of Maier and Meier [105]:

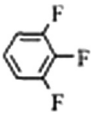
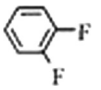
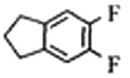
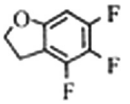
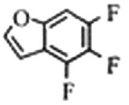
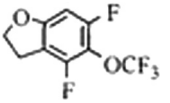
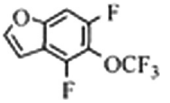
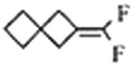
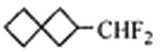
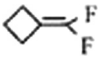
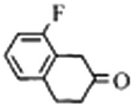
$$\Delta\varepsilon = NhF/\varepsilon_o[\Delta\alpha - F\mu^2/kT(1 - 3\cos^2\beta)]S, \quad (1)$$

where $h = 3\varepsilon^*/(2\varepsilon^* + 1)$, $\varepsilon^* = (\varepsilon_{||} + 2\varepsilon_{\perp})/3$; $\Delta\alpha = (\alpha_{||} - \alpha_{\perp})$ is the polarizability anisotropy; F is the cavity reaction field; μ is the dipole moment; β is the angle between the molecular long axis and the dipole moment, and N is the number of molecules per unit volume; S is the order parameter.

It is evident from Table 1 that the introduction of cyclopentane into the molecular core of liquid crystals slightly increases their dielectric anisotropy in comparison

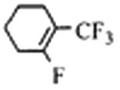
Table 6. Physico-chemical properties of liquid crystals:



No.	A	Phase transitions, °C	$\Delta\varepsilon^a$	Δn^a	$\gamma_1{}^a$, mPas	Ref.
6-1		Cr 66 N 94.1 I Cr 64.7 N 93.7 I	9.7 5.5[b]	0.075 0.078[b]	171 25.5[c,d]	[61] [62]
6-1		Cr 46 N 124 I	6.4	0.079		[63]
6-2		Cr 54 SmB 92 I				[64]
6-3		Cr 142 N 198 I	8.5	0.109		[42]
6-4		Cr 89 I	9.3	0.063	524.0	[49]
6-5		Cr 90 N 173.9 I	13.8	0.123	512.0	[49]
6-6		Cr 93 I	10.6	0.066	689.0	[49]
6-7		Cr 97 N 151 I	14.4	0.116	668.0	[49]
6-8		Cr 58 SmB 151 N 157.41	3.7	0.082	17.0[y]	[65]
6-9		Cr 37 SmB 191 1	1.5	0.077	42.0[y]	[65]
6-10		Cr 54 SmB 91 N 103.8 I	3.0 4.2	0.058 0.073	 10.0[y]	[66] [47]
6-11		Cr 111.6 N 168.5 I				[67]

(*Continued*)

Table 6. Continued

No.	A	Phase transitions, °C	$\Delta\varepsilon^a$	Δn^a	$\gamma_1{}^a$, mPas	Ref.
6-12		Cr 116 N 129.2 I	10.4	0.063		[68]

[a]Extrapolated from 10 wt% solution in ZLI-4792 at 20°C.
[b,c]Extrapolated from 15 wt% solution in liquid crystal material at 25°C and 20°C, respectively.
[d]volume viscosity η [mPas].
[e]kinematic viscosity v [mm^2s^{-1}].

with that of the corresponding trans-1,4-cyclohexylene derivatives (compounds **1-3, 1-4**). It is rough comparison since we have to compare the results of the direct measurements with the extrapolated data. In the case of the indan derivatives, the number and positions of the lateral fluorine (chlorine) atoms introduced into indan play very important role in defining the sign and value of the dielectric anisotropy of these derivatives (see Eq. (1)). It can be illustrated by the positive dielectric anisotropy of compounds **4-1, 4-2, 5-1, 6-3** and negative dielectric anisotropy of compounds **5-4, 7-1, 7-3** presented in Tables 4–7. It is obvious from these tables that the indan derivatives show the high (absolute) values of the dielectric anisotropy among compounds under consideration.

4. Optical Properties

The phenomenological relation between the refractive index and the electric polarization is defined as [106,107]:

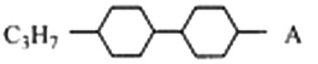
$$(n^{*2} - 1)/(n^{*2} + 2) = N\alpha^*/3\varepsilon_o, \tag{2}$$

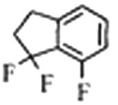
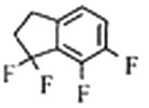
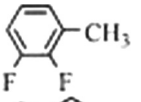
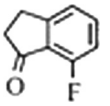
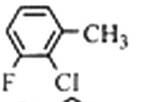
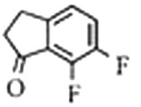
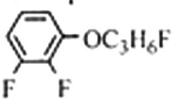
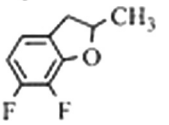
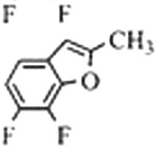
where the mean polarizability $\alpha^* = (\alpha_\parallel + 2\alpha_\perp)/3$; the mean refractive index $n^{*2} = (n_e^2 + 2n_o^2)/3$; n_o is the ordinary, and n_e is the extraordinary refractive indices. As supposed, Eq. (2), previous paragraph and polarizability data should explain the moderate optical properties of the indan derivatives presented in Tables 4–7. As expected, increasing the number of lateral fluorine atoms or/and number of the saturated rings in the fragments of reference compounds usually lowers their optical anisotropy.

5. Viscous Properties

It has been shown that the nematic liquid crystalline materials for display applications should have a low viscosity for giving the acceptable response times to liquid crystal displays [108,109]. The rotational viscosity γ_1 of a nematic liquid crystal (NLC) is a dissipative coefficient describing the rate of reorientation of the NLC director [110]. The magnitude of the rotational and flow viscosities depend on molecular structure, intermolecular association, and temperature [111,112]: as temperature increases, viscosity decreases [111–114].

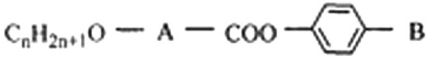
Table 7. Physico-chemical properties of liquid crystals:

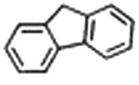
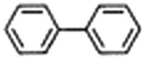
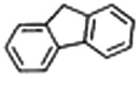
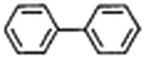
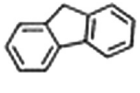
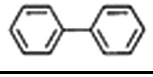


No.	A	Phase transitions, °C	$\Delta\varepsilon^a$	Δn^b	Ref.
7-1		Cr l71 SmB (l70) N (170.7) I	−5.4	0.075	[69]
7-2		Cr 35 SmB 143 I	−2.5	0.042	[70]
7-3		Cr 130 SmB 168 N 203.7 I	−8.3	0.075	[69]
7-4		Cr 67 N 145.3 I	−2.8	0.095	[71]
7-5		Cr 122 I	−8.5	0.075	[69]
7-6		Cr 61.1 SmB 74.2 N 108.6 I	−2.6[c]	0.090[c]	[72]
7-7		Cr 118 I	−11.4	0.065	[69]
7-8		Cr 109.3 N 168.3 I	−4.5[c]	0.092[c]	[73]
7-9		Cr 63 SmB 137 I	−6.0	0.030	[70]
7-10		Cr I12 N (105.1) I	−6.7	0.073	[57]
7-11		Cr 89 N 173.6 I	−5.4	0.117	[57]

[a]Extrapolated from 10 wt% solution in ZLI-2857 at 20°C.
[b]Extrapolated from 10 wt% solution in ZLI-4792 at 20°C.
[c]ExirapoJated from 15 wt% solution in liquid crystal material at 25°C.

Table 8. Physico-chemical properties of liquid crystals:



No.	n	A	B	Phase transitions, °C	$\|P_s{}^a\|$, nCcm^{-2}	Θ^a, degr.	Ref.
8-1	8		$OCH_2C^*H(CH_3)C_2H_5$	Cr 117 SmC^* (l09) SmA 201 I			[80]
8-2	8		$OCH_2C^*H(CH_3)C_2H_5$	Cr 100.2 SmB 105.8 SmC^* 144.9 SmA 189.3 I			[81]
8-3	8		$COOC^*H(CH_3)C_6H_{13}$	Cr l21 SmC^*_A (105.7) SmC^*_y (l08.1) SmC^* l09.9 SmA 152.8 I			[82]
8-4	8		$COOC^*H(CH_3)C_6H_{13}$	I 148 SmA 122 SmC^*_α 120.9 SmC^* 119.2 SmC^*_y, 118.4 SmC^*_A 65 Cr			[83]
8-5	10		$OC^*H(CH_3)C_6H_{13}$	Cr 87 SmC^* 123 SmA 149 I	50	21	[84]
8-6	10		$OC^*H(CH_3)C_6H_{13}$	Cr 70 SmC^* 125 SmA 143 I	70	29	[84]

$^a T_{meas} = T_{SmC^*\text{-}SmA} - 40°C$.

As is evident from Table 1 and [33], the cyclopentane derivatives exhibit lower values of the kinematic viscosity compared with those of the corresponding trans-1,4-cyclohexylene derivatives. It can be explained by a smaller size of cyclopentane in comparison with that of cyclohexane.

According to the results on flow and rotational viscosity presented in Tables 4–6, the indan derivatives show the moderate values of the viscosity. While increasing the number of lateral fluorine atoms and/or rings in the fragments of reference compounds usually enhances their viscosity.

6. Physical Properties of the Smectic C* Phase

The spontaneous polarization P_s of the smectic C* liquid crystals is an important parameter due to its linear coupling with an applied electrical field which is the basis of the application of these materials [115]. The polarization is caused by the cramped rotation of the dipoles of the molecules and varies with the position of these dipoles with respect to the chiral group [115]. The spontaneous polarization P_s is a quantity which is directly related to the response time τ as a switching device [116]:

$$\tau = \gamma_\varphi \sin^2 \Theta / P_s E, \tag{3}$$

where γ_φ is the rotational viscosity, which refers to the rotation about an axis perpendicular to the director **n** and P_s, Θ is the tilt angle, E is an applied electric field.

According to Scherowsky and Sefkow [117], liquid crystals should have the following structural features in order to obtain high spontaneous polarization:

(1) A high dipole moment perpendicular to the longitudinal molecular axis;
(2) Short distances between the chiral center and the lateral dipole and the mesogenic part respectively;
(3) A restriction of free rotation in the chiral region.

It is evident from Table 2 that the replacement of cyclopentane by cyclohexane increases the spontaneous polarization (compounds **2-5, 2-6**), while the fluorene derivative **8-5** exhibits lower values of the spontaneous polarization and tilt angle compared with those of the corresponding biphenyl derivative **8-6** (Table 8).

7. Conclusion

Systematic studies on introducing cyclopentane and cyclopentane-based fragments into the molecular structure of liquid crystals on the creation of the mesophases and their physico-chemical properties have been performed, with attempts to correlate the molecular level parameters with the observed properties. The information here presented may lead to a better understanding of the nature of liquid crystals.

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