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Synthesis and physical properties of novel liquid crystal oligomers possessing polar terminal groups

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A homologous series of novel liquid crystal oligomers possessing 4-fluorobiphenyl and 4-trifluoromethoxyphenyl benzoate moieties was prepared and the physical properties investigated. The dimesogenic compounds, 4-trifluoromethoxyphenyl 4-{6-[4-(4-fluorophenyl)phenyloxy]alkoxy}benzoates, exhibited nematic (N) and smectic A (SmA) phases. Pronounced odd–even effects were seen, not only for the phase transition but also for the induced dielectric anisotropy in the N phase of the mixture with a host material, on varying the spacer length of the dimeric compounds. The λ–shaped trimesogenic compound, 4-trifluoromethoxyphenyl 3,4-bis{6-[4-(4-fluorophenyl)phenyloxy]hexyloxy}benzoate, was found to show monotropic N and SmA phases. We discuss oligomeric effects of the mesogenic moieties on the phase transition behaviour, and on the induced dielectric anisotropy.

1. Introduction

Supramolecular assemblies composed of oligomeric liquid crystals are current topics in the design of liquid crystalline materials [1]. Liquid crystal oligomers consist of semi-rigid mesogenic units connected by flexible spacers [2–4]. Dimeric liquid crystals are of interest because they exhibit different properties from the corresponding low molar mass mesogens. For example, the transition properties of dimeric liquid crystals are known to depend on the length and parity of the flexible spacer. Liquid crystal trimers [5] and tetramers [6] have also been reported. Pronounced odd–even effects have been observed in the transition properties of linear liquid crystal oligomers of varying spacer length; the transition behaviour is interpreted in terms of the average molecular shape of those oligomers. U-shaped liquid crystals have been investigated by several research groups [7–10]. Attard and Douglass reported property–structure correlations of bimesogenic compounds derived from phthalic acid, providing important understanding about the U-shaped liquid crystal system [10]. In the banana-shaped 1, 3-benzene derivatives first synthesized by Matsunaga *et al.* [11], antiferroelectric and ferroelectric properties have recently been found by Watanabe *et al.* [12, 13]. The banana-shaped system has provided new concepts for chirality and phase structures in liquid crystals [14, 15].

We have designed several novel pre-organized systems: a flexible dimesogenic compound [16], a U-shaped molecule [17], a binaphthyl derivative [18], a λ–shaped molecule [19], V-shaped [20], T-shaped [21] and Y-shaped molecules [22]; these pre-organized supermolecules were found to induce unusual ordering in the supramolecular liquid crystalline phase. We recently reported that some U-shaped compounds induce large dielectric anisotropy in their nematic mixtures and reduce the threshold voltage [23, 24]. We prepared the corresponding linear-shaped compounds with a flexible spacer and investigated the effect of spacer length on the physical properties [24, 25]. However none of the linear-shaped compounds showed any liquid crystalline phase; and we obtained no information on the relationship between dielectric anisotropy and linear molecular shape of the compounds in the nematic phase, or in the nematic mixture with a host material.

We report here the synthesis and physical properties of novel liquid crystal oligomers (figure 1) possessing 4-fluorobiphenyl and 4-trifluoromethoxybenzoate moieties, and discuss oligomeric effects of the mesogenic moieties on the phase transition behaviour, and on the induced dielectric anisotropy.

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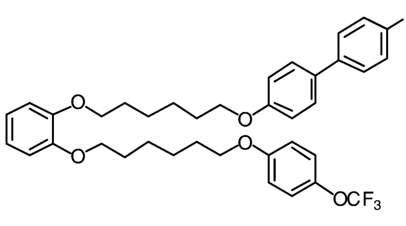
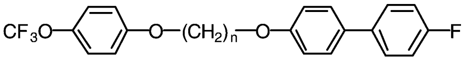


U-shaped compound



Linear-shaped compound

Figure 1. Molecular structures of the U-shaped and linear-shaped compounds with a flexible spacer.

2. Experimental

2.1. *Preparation of Materials*

Purification of the final product was carried out using column chromatography over silica gel (63–210 μm) (Kanto Chemical Co., Inc.) using a toluene/ethyl acetate mixture as the eluant, followed by recrystallization from ethanol. The structure of the final product was elucidated using infrared (IR) spectroscopy (FTS-30; Bio-Rad Laboratories, Inc.) and proton nuclear magnetic resonance spectroscopy (JNM-GX270, JEOL; or JNM-A400, JEOL). Elemental analysis (EA, 1110; CE Instruments) was obtained for each final compound.

2.1.1. 4-Trifluoromethoxyphenyl 3,4-bis{6-[4-(4-fluorophenyl)phenyloxy]hexyloxy}benzoate, V-(6, 6). Potassium carbonate (0.97 g, 7 mmol) was added to a solution of 1, 6-dibromohexane (2.21 g, 9 mmol) and 4-fluoro-4′-hydroxybiphenyl (1.32 g, 7 mmol) in cyclohexanone (20 ml). The reaction mixture was stirred at 80°C for 5 h. After filtration of the precipitate, the solvent was removed by evaporation. The residue was purified by column chromatography on silica gel with toluene/hexane (6/4). 4-(6-Bromohexyloxy)-4′-fluorobiphenyl (**1**) was obtained; yield 0.62 g (25%).

Compound **1** (2.0 g, 5.7 mmol) and ethyl 3,4-dihydroxybenzoate (0.49 g, 2.7 mmol) were dissolved in cyclohexanone (20 ml). K_2CO_3 (0.79 g, 5.7 mmol) and KI (0.05 g, 0.5 mmol) were added and the resulting mixture stirred at 120°C for 9 h. The reaction mixture was filtered and the solvent removed by evaporation under reduced pressure. The product was purified by column chromatography using a toluene/ethylacetate (9/1) mixture as eluant. Ethyl 3,4-bis{6-[4-(4-fluorophenyl)phenyloxy]hexyloxy}benzoate (**2**) was obtained; yield 1.66 g (86%).

Compound **2** (1.64 g, 2.3 mmol) was added to a solution of KOH (0.63 g, 11.3 mmol) in a water/ethanol (1/9) mixture (170 ml). The resulting mixture was stirred under reflux for 7 h, and the solution acidified with HCl. The aqueous phase was extracted with dichloromethane (600 ml), and the organic extracts evaporated. 3,4-Bis{6-[4-(4-fluorophenyl)phenyloxy]hexyloxy}benzoic acid (**3**) was obtained; yield 1.19 g (75%).

To a solution of compound **3** (0.65 g, 0.9 mmol) in dichloromethane (20 ml), 4-trifluoromethoxyphenol (0.17 g, 0.9 mmol), *N*,*N*′-dicyclohexylcarbodiimide (0.2 g, 1 mmol), and 4-(*N*,*N*-dimethylamino)pyridine (0.01 g, 0.1 mmol) were added. The resulting solution was stirred at room temperature for 8 h. Precipitated materials were removed by filtration, and the solvent by evaporation removed. The residue was purified by column chromatography on silica gel by using a toluene/ethyl acetate (20/1) mixture as eluant. Recrystallization from ethanol gave the desired product **V-(6,6)**; yield 0.48 g (47%). ^{1}H NMR (400 MHz, solvent $CDCl_3$, standard TMS) δ_H/ppm: 7.84(d, 1H, Ar–**H**, $J=8.3$ Hz), 7.68(s, 1H, Ar–**H**), 7.51–7.44(m, 8H, Ar–**H**), 7.31–7.24(m, 4H, Ar–**H**). 7.10(dd, 4H, Ar–**H**, $J=8.8$ Hz, $J=8.8$ Hz), 6.98–6.94(m, 5H, Ar–**H**), 4.15(t, 2H, Ar–OC**H**$_2$–, $J=7.1$ Hz), 4.12(t, 2H, Ar–OC**H**$_2$–, $J=7.1$ Hz), 4.02(t, 2H, Ar–OC**H**$_2$–, $J=6.6$ Hz), 4.01(t, 2H, Ar–OC**H**$_2$–, $J=6.4$ Hz), 1.96–1.61(m, 16H, aliphatic–**H**). IR (KBr) ν_{max}/cm^{-1}: 2940, 2867, 1731, 1602, 1499, 1430, 1183, 1143. EA: calc. for $C_{50}H_{47}F_5O_7$, C 70.25; found, C 70.17%.

The other compounds presented in this paper were obtained by a similar method to that for compound **V-(6, 6)**.

2.1.2. 4-Trifluoromethoxyphenyl 4-{6-[4-(4-fluorophenyl)phenyloxy]hexyloxy}benzoate, III-6. ^{1}H NMR (270 MHz, solvent $CDCl_3$, standard TMS) δ_H/ppm: 8.12(d, 2H, Ar–**H**, $J=8.8$ Hz), 7.51–7.43(m, 4H, Ar–**H**), 7.25–7.21(m, 4H, Ar–**H**). 7.08(dd, 2H, Ar–**H**, $J=8.8$ Hz, $J=8.8$ Hz), 6.97(d, 2H, Ar–**H**, $J=8.4$ Hz), 6.95(d, 2H, Ar–**H**, $J=8.6$ Hz), 4.07(t, 2H, Ar–OC**H**$_2$–, $J=6.8$ Hz), 4.02(t, 2H, Ar–OC**H**$_2$–, $J=6.6$ Hz), 1.88–1.58(m, 8H, aliphatic–**H**). IR (KBr) ν_{max}/cm^{-1}: 2940, 2861, 1733, 1607, 1501, 1430, 1165, 1083. EA: calc. for $C_{32}H_{28}F_4O_5$, C 67.60; found C 67.88%.

2.1.3. 4-Trifluoromethoxyphenyl 3-{6-[4-(4-fluorophenyl)phenyloxy]hexyloxy}benzoate, IV-6. ^{1}H NMR (400 MHz, solvent $CDCl_3$, standard TMS) δ_H/ppm: 7.76(d, 1H, Ar–**H**, $J=7.8$ Hz), 7.67(s, 1H, Ar–**H**), 7.49–7.38(m, 5H, Ar–**H**), 7.28–7.21(m, 4H, Ar–**H**), 7.17(d, 1H, Ar–**H**, $J=7.8$ Hz), 7.08(dd, 2H, Ar–**H**, $J=8.8$ Hz, $J=8.8$ Hz), 6.94(d, 2H, Ar–**H**, $J=8.8$ Hz), 4.04(t, 2H, Ar–OC$\mathbf{H}_2$–, J=6.3 Hz), 4.00(t, 2H, Ar–OC$\mathbf{H}_2$–, J=6.6 Hz), 1.87–1.53(m, 8H, aliphatic–**H**). IR (KBr) ν_{max}/cm^{-1}: 2945, 2873, 1731, 1603, 1501, 1445, 1161. EA: calc. for $C_{32}H_{28}F_4O_5$, C 67.60; found C 67.44%.

2.1.4. 4-Cyanophenyl 3,4-bis{6-[4-(4-fluorophenyl)-phenyloxy]hexyloxy}benzoate, VI-(6,6). ^{1}H NMR (400 MHz, solvent $CDCl_3$, standard TMS) δ_H/ppm: 7.83(d, 1H, Ar–**H**, J=8.6 Hz), 7.75(d, 2H, Ar–**H**, J=8.8 Hz), 7.66(s, 1H, Ar–**H**), 7.51–7.44(m, 8H, Ar–**H**), 7.37(d, 2H, Ar–**H**, J=8.8 Hz), 7.10(dd, 4H, Ar–**H**, J=8.6 Hz, J=8.6 Hz), 6.98–6.94(m, 5H, Ar–**H**), 4.14(t, 2H, Ar–OC$\mathbf{H}_2$–, J=4.9 Hz), 4.10(t, 2H, Ar–OC$\mathbf{H}_2$–, J=4.9 Hz), 4.02(t, 2H, Ar–OC$\mathbf{H}_2$–, J=6.4 Hz), 4.01(t, 2H, Ar–OC$\mathbf{H}_2$–, J=6.6 Hz), 1.94–1.59(m, 16H, aliphatic–**H**); IR (KBr) ν_{max}/cm^{-1}: 2940, 2864, 2229, 1730, 1602, 1499, 1431, 1164, 1142. EA: calc. for $C_{50}H_{47}F_2NO_6$, C 75.45; found C 75.17%.

2.2. *Physical properties*

The initial assignments and corresponding transition temperatures for the final products were determined by thermal optical microscopy using a Nikon Optiphoto POL polarizing microscope equipped with a Mettler FP82 microfurnace and FP80 control unit. The heating and cooling rates were 5°C min^{-1}, unless otherwise indicated. Temperatures and enthalpies of transition were investigated by differential scanning calorimetry (DSC) using a Seiko DSC 6200 calorimeter. The compounds were studied at a scanning rate of 5°C min^{-1}, for both heating and cooling cycles, after encapsulation in aluminum pans. Dielectric measurements were performed using an impedance analyser (HP 4284A; Hewlett Packard Co.) with a temperature control unit at a frequency of 1 kHz [26]. A sample was contained in a homogeneous configuration cell (5.0 μm) where the inner surfaces had been coated with polyimide aligning agent and buffed unidirectionally (E. H. C. Co., Ltd). The dielectric measurements were performed using the single cell method and carried out three times at each measured value. The experimental error was within ±0.7%.

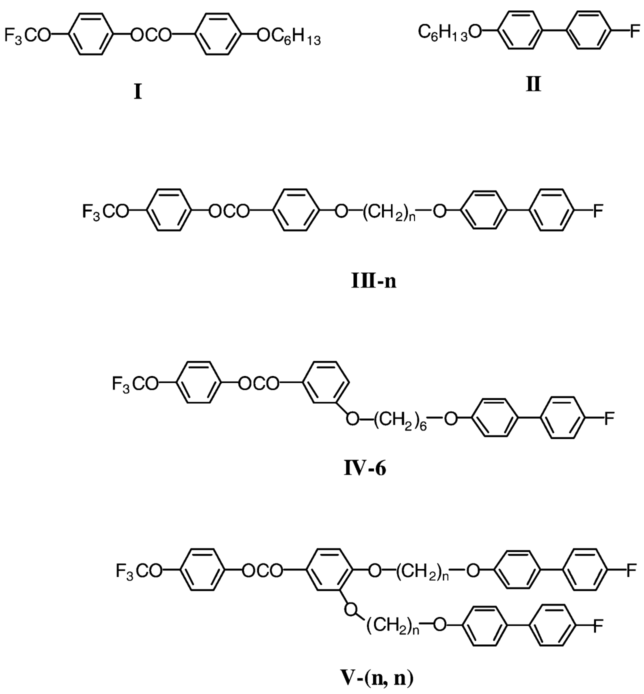


Figure 2. Molecular structures of liquid crystalline oligomers possessing fluoro groups.

3. Results and discussion

3.1. *Phase transition properties*

Figure 2 shows the molecular structures of the newly prepared oligomeric compounds and the corresponding monomeric compounds. Table 1 gives the temperatures and enthalpies of transition for these compounds, determined by optical microscopy and DSC.

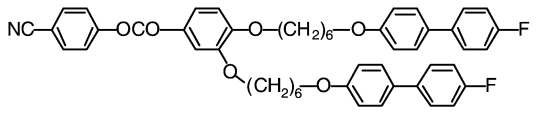
Table 1. Transition temperatures (°C) on cooling and enthalpies (kJ mol^{-1}) of transition (in brackets) for compounds under investigation.

Compound	Cryst	SmX[a]	SmA	N	I	m.p.
I	• 36		• 81 (5.84)		•	56
II	• 77				•	78
III-6	• 90		• 125 (1.02)	• 153 (5.48)	•	130
III-7	• 46	• 63[b]	• 64[b]	• 105 (1.27)	•	98
III-8	• 106		• 135 (2.76)	• 141 (5.80)	•	140
IV-6	• 58				•	106
V-(6,6)	• 98		• 119 (5.58)	• 129 (8.95)	•	152
V-(7,7)	• 88				•	135

[a]SmX: unidentified smectic phase. [b]The N–SmA and SmA–SmX transitions occurred simultaneously. The total value of both transition enthalpies was 2.96 kJ mol^{-1}.

The monomeric compound **I** exhibited an enantiotropic SmA phase whereas compound **II** showed no liquid crystalline phase [24]. The dimesogenic compounds **III-6**, **III-7** and **III-8** in which 4-fluorobiphenyl and 4-trifluoromethoxyphenyl benzoate moieties are connected via a flexible spacer were found to show N and SmA phases, and compound **III-7** exhibited a higher ordered unidentified smectic phase below the SmA phase. Pronounced odd–even effects are seen for the I–N and N–SmA transition temperatures of the dimesogenic compounds. The entropy changes, $\Delta S/R$, for the I–N transition of compounds **III-6**, **III-7** and **III-8** were 1.55, 0.40 and 1.69, respectively. Imrie and Luckhurst give the following interpretation for odd–even effects on the transition properties of dimesogenic compounds [2]. In the isotropic phase approximately half the conformers of an even-membered dimer are essentially linear whereas for an odd-membered dimer just 10% are linear. There exists a synergy between conformational and orientational order, and hence at the transition to the nematic phase for even-membered dimers many of the bent conformers are converted to a linear form. This enhances the orientational order of the nematic phase resulting in a larger nematic–isotropic entropy than would be expected for a monomer. For odd-membered dimers, however, the difference in free energy between the bent and linear conformers is such that the orientational order of the nematic phase is insufficient to convert bent into linear conformers. Hence, the orientational order is not enhanced and a smaller nematic–isotropic entropy would be expected.

The marked odd–even effects for the I–N transition properties of compounds **III-6**, **III-7** and **III-8** are consistent with the above interpretation. Compound **IV-6**, which is thought to form a bent structure, did not show a liquid crystalline phase. The λ–shaped compound **V-(6,6)** , in which compounds **III-6** and **IV-6** are incorporated, exhibited monotropic N and SmA phases, on the other hand, compound **V-(7,7)** with odd-membered spacers did not show a liquid crystalline phase. In order to investigate the effect of the terminal polar group, we prepared compound **VI-(6,6)** that has a cyano group instead of the trifluoromethoxy group of compound **V-(6,6)**. The molecular structure and transition temperatures are shown in figure 3. Compound **VI-(6,6)** exhibited exclusively nematic behaviour, which is attributed to intermolecular antiparallel interactions between the cyanophenyl moieties.



VI recryst 112 N 141 (7.3) Iso mp 148

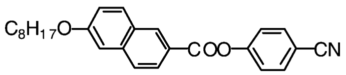
Figure 3. Molecular structure, transition temperatures (°C) on cooling and enthalpies (kJ mol^{-1}) of transition in brackets for compound **VI-(6,6)**.

3.2. *Dielectric anisotropy*

We used 4-cyanophenyl 6-octyloxynapthalene 2-carboxylate (host **A**) as a host material to investigate the dielectric anisotropy of the oligomeric compounds (figure 4). The transition temperature, the parallel and perpendicular components of the dielectric constant, and the dielectric anisotropy of a mixture consisting of host **A** and 10 wt% of each added compound are listed in table 2. For comparison, those values induced by an equimolar mixture of the monomeric compounds **I** and **II** are also shown.

The liquid crystal oligomers were found to induce smaller values of $\Delta\varepsilon$ in the mixture than the corresponding monomeric compounds or the equimolar mixture. This behaviour was also observed for the previously reported dimesogenic system [25]. Dielectric anisotropy induced by compound **III-6** or **III-8** in the mixture with host **A** is smaller than that of host **A**, whereas that induced by compound **III-7** is larger. Extrapolated values of compounds **III-6** and **III-7** from the observed $\Delta\varepsilon$ at T_{IN}-20°C in the mixture with host **A** are +4.1 and +14.7, respectively. On the other hand, observed values at T_{IN}-20°C of those compounds **III-6** and **III-7** in their N phases were +1.9 and +2.1, respectively. Odd–even effects are seen for the extrapolated $\Delta\varepsilon$ values of those compounds; however, the effects are not seen for the observed $\Delta\varepsilon$ values. There is a marked difference in $\Delta\varepsilon$ of compound **III-7** between the extrapolated and observed values.

Odd–even effects are seen for the T_{IN} of the mixtures, indicating that there is significant difference in molecular shape between compounds **III-6** and **III-7** in their mixtures. As discussed above, if we assume an all-*trans* conformation for the spacer of those compounds, the two mesogenic units of compound **III-6** are almost parallel, but those of compound **III-7** are not. Compound **IV-6**, which is thought to have a more bent structure than compound **III-7**, induces a larger $\Delta\varepsilon$ in the mixture than compound **III-7**. The λ–shaped compound **V-(6,6)** was found to induce larger $\Delta\varepsilon$ in



Host A

Figure 4. Molecular structure of host **A**.

Table 2. Transition temperature (°C), parallel component ($\varepsilon_{//}$) and perpendicular component ($\varepsilon_{\perp}$) of dielectric constant,[a] and dielectric anisotropy ($\Delta\varepsilon$) of a mixture consisting of host **A** and 10 wt% of each compound.

Compound	T_{IN}	$\varepsilon_{//}$	$\varepsilon_{\perp}$	$\Delta\varepsilon$
Host **A**	135	19.3	7.4	11.9
I	124	20.4	7.4	13.0
II	124	19.2	7.1	12.1
I-II mixture[b]	119	19.2	6.9	12.3
III-6	135	18.1	7.0	11.1
III-7	128	18.9	6.7	12.2
III-8	132	18.8	7.1	11.7
IV-6	114	20.6	8.0	12.6
V-(6,6)	128	18.9	7.0	11.9

[a]Dielectric measurements were performed at T_{IN}-20°C with a frequency of 1 kHz. [b]**I-II** mixture: an equimolar mixture of compounds **I** and **II**.

the mixture than **III-6** but a smaller $\Delta\varepsilon$ than compound **IV-6**. The λ–shaped compound **VI-(6,6)**, possessing a –CN group, induced 11.9 of $\Delta\varepsilon$ at T_{IN}-20°C in the N phase of the mixture. The $\Delta\varepsilon$ induced by compound **VI-(6,6)** is the same as that induced by compound **V-(6,6)**.

The dielectric anisotropy of a uniaxial liquid crystalline phase can be described as

$$\Delta\varepsilon = (NhFS)(\varepsilon_0)^{-1}\left[\Delta\alpha - \mu^2 F(2k_{\mathrm{B}}T)^{-1}\left(1-3\cos^2\beta\right)\right] \quad (1)$$

where F and h are the reaction field and cavity field factors that account for the field-dependent interaction of a molecule with its environment, N is the number density, S is the order parameter, μ is the dipole moment, $\Delta\alpha$ is the molecular polarizability anisotropy, and β is the angle between the dipole moment vector and the effective orientation axis of the liquid crystal molecule [27].†

First we discuss the values of $\Delta\varepsilon$ induced by each dimesogenic compound in its N phase, which are smaller than those induced by the monomeric compounds. Figure 5 shows a molecular organization model for the N phase consisting of compound **III-6** and host **A**. Directions of the C–OCF3 and C–F of compound **III-6** are almost inverse within a single molecule, which results in a small $\Delta\alpha$. Thus the dimesogenic compounds induced smaller values of $\Delta\varepsilon$ than did the corresponding monomeric compounds.

The larger $\Delta\varepsilon$ induced by compound **III-7** than that by compound **III-6** is attributed to an increase in the parallel component of the dielectric constant. The significant large $\Delta\varepsilon$ induced by compound **IV-6** can also result from a marked increase of the parallel component of the dielectric constant. The increase of the parallel component may result from an increase in the effective dipole moment of the system, i.e. the dipole moment along the director that constitutes the coupling between μ and β. Thus, the large $\Delta\varepsilon$ induced by compounds **III-7** or **IV-6** is interpreted in terms of conformational change, in that compounds **III-7** and **IV-6** form not a bent structure, but an almost U-shaped structure in host **A** as shown in figure 6 [24].

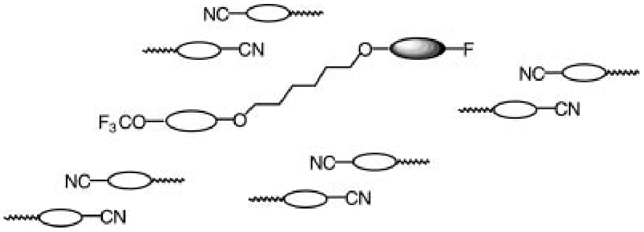


Figure 5. A possible model for molecular organization of a mixture consisting of **III-6** and host **A**.

There is another possible reason for the increase of $\Delta\varepsilon$. Our previous studies on a homologous series of linear-shaped compounds, the $\propto$-(4-trifluoromethoxyphenyloxy)-ω-[4-(4-fluorophenyl)phenyloxy]alkanes (see figure 1, n=6–12), showed that the compounds with a longer central spacer (n=11, 12) only induced larger $\Delta\varepsilon$ in the mixture with 6OCB [25]. These results indicate that only the linear-shaped compounds with a long and flexible spacer can form a U-shaped conformation. It seems to be difficult for compounds **III-7** and **IV-6** to form such a U-shaped structure, because the spacer length is too short for the conformation. Furthermore, if compound **III-7** formed

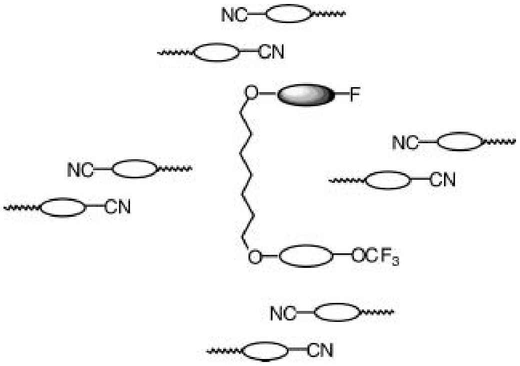


Figure 6. A molecular conformation model for compound **III-7** in host **A**.

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† In equation (1), F denotes the reaction field factor [F=1/(1−$f\alpha$); f=(ε−1)/2$\pi\varepsilon a^3$(2ε+1)], and h the cavity factor [h=3ε/(2ε+1)]. The macroscopic dielectric constant is used for ε.

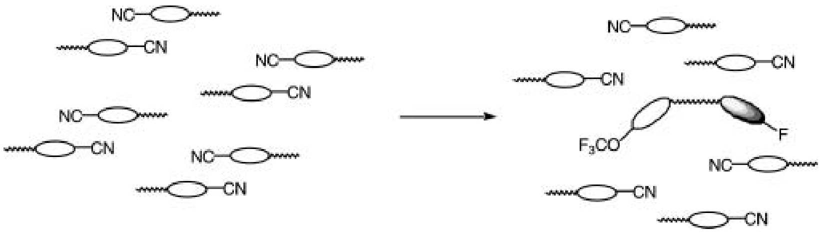

Figure 7. A possible model for the effect of molecular biaxiality on organization of the host molecules.

a U-shaped structure, the induced value of $\Delta\varepsilon$ should be much larger than that induced by the monomeric compound [25]. The alternative explanation for the increase of $\Delta\varepsilon$ is that the bent-formed dimesogenic compound can affect the organization of the host molecules in the nematic mixture, which results in an increase of $\Delta\varepsilon$ of the system (see figure 7). With respect to the λ–shaped compounds **V-(6,6)** and **VI-(6,6)**, $\Delta\alpha$ of **VI-(6,6)** possessing a –CN group is thought to be larger than that of **V-(6,6)** possessing a –OCF$_3$ group; however, there is no difference between them in the induced $\Delta\varepsilon$. These results also suggest that the molecular shape of an additive plays an important role in the induced $\Delta\varepsilon$ of the mixture. Further investigation is necessary to clarify this hypothesis.

Reduced driving voltage is an important requirement for LCD improvement. Liquid crystalline materials with high dielectric anisotropy ($\Delta\varepsilon$) are known to decrease the threshold voltage (V_{th}) of the electro-optical response of a dielectrically positive liquid crystal mixture. Consequently, they decrease the driving voltage of a twisted-nematic (TN) display. On the other hand, a high voltage holding ratio (VHR) of the liquid crystal is necessary for thin film transistor (TFT) LCDs. A molecule possessing a polar group, such as –CN, induces large $\Delta\varepsilon$ but lowers the VHR. The present results indicate a possibility that a bent-shaped additive may increase $\Delta\varepsilon$ of the nematic mixture without decreasing the VHR.

4. Conclusions

A homologous series of novel liquid crystal oligomers containing 4-fluorobiphenyl and 4-trifluoromethoxyphenyl benzoate moieties was prepared. Odd–even effects were seen for the phase transition behaviour of these dimesogenic compounds. Furthermore, a λ-shaped mesogenic trimer with even-numbered spacers exhibited monotropic N and SmA phases, however, a mesogenic trimer with odd-numbered spacers did not exhibit a liquid crystalline phase. The dimesogenic compounds in which the mesogenic units are thought to be bent, were found to induce larger dielectric anisotropy in a mixture with a host nematic material, than that seen for similar compounds in which the mesogenic units are coparallel.

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