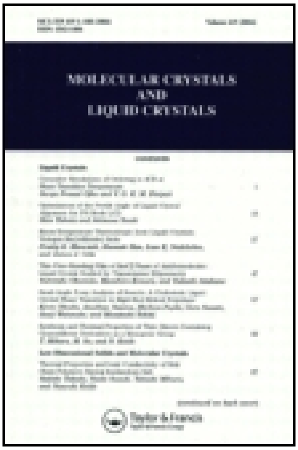

Molecular Crystals and Liquid Crystals

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Synthesis and Mesomorphic Studies of a Series of Liquid Crystalline 2-(4-Alkylphenyl)-6-Methoxyquinolines

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Synthesis and Mesomorphic Studies of a Series of Liquid Crystalline 2-(4-Alkylphenyl)-6-Methoxyquinolines

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This study describes the novel synthesis of a homologous series of quinoline-containing liquid crystalline 2-(4-alkylphenyl)-6-methoxyquinolines (nPQOMe, n = 4–8) compounds. Preparation of these compounds was completed in the overall two-step reaction and fair to good yields (47–60%) were obtained. Thermotropic behaviors of these liquid crystalline compounds were investigated using differential scanning calorimetry and polarized optical microscopy. Liquid crystals of these 2-(4-alkylphenyl)-6-methoxyquinolines display only nematic phase.

Keywords: liquid crystals; quinoline-containing compounds; synthesis; thermal analysis

1. INTRODUCTION

Advances in the fields such as the applications, the physics, or the theory of liquid crystals depend very critically upon the organic chemist and his role in synthesizing materials. Since a single liquid crystal shows a couple of distinguished properties at best, mixtures consisting of up to twenty or more polar and weakly polar compounds have to be developed for a given application. Therefore, we believe that there is still room for improvements in prepararion of new nematic liquid crystals and devising novel molecular synthesizing methodologies [1–2].

Some quinoline-containing liquid crystalline compounds were synthesized in past years. Some were synthesized by reacting suitable substituted anilines and benzaldehydes with piruvic acid [3], whereas some other compounds were prepared by heating aniline with

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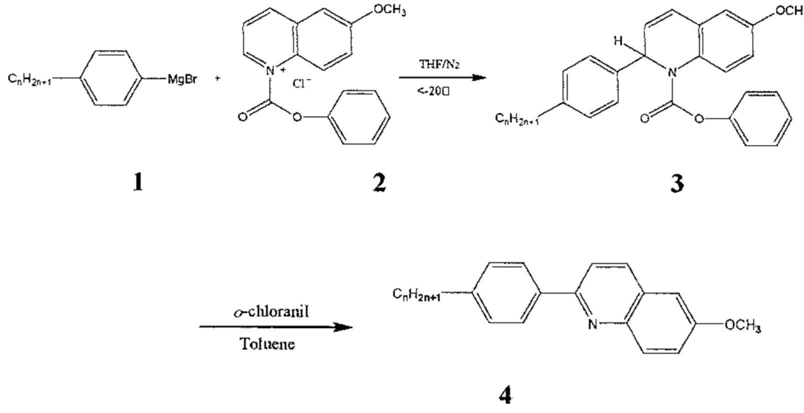
glycerin, or 1,2-glycols or *α,β*-unsatuaturated aldehyde through Skraup procedure or Doebner–von Miller variation [4–9]. Another study reported bis-formulation of acetanilides followed by cyclization with PPA and then converted into chloroquinoline aldehydes, which were used as an intermediate for further synthesis of quinoline-containing liquid crystalline compounds [10–12]. Although these methods are of great value for constructing important heterocyclic systems, most suffer from limited scope of the method applied, large number of synthetic steps and relatively low yields. On the other hand, some recent patents showed high-speed response of optical switching element was achieved by quinoline-containing liquid crystalline compounds [13–15]. All these reasons prompted us to seek a new synthetic method for preparing such liquid crystalline compounds.

Previously, we prepared various 2- or 4-substituted pyridines and alkaloids by regioselective addition of organometallic reagents to l-acylpyridinium salts [16–18]. Recently, we have successfully applied this methodology to prepare some pyridine-containing liquid crystals [19,20]. In this article, we extended the same synthetic methodology to the synthesizing 2-(4-alkylphenyl)-6-methoxyquinolines (nPQOMe), in which the alky chain length varied from butyl to octyl.

2. RESULTS AND DISCUSSION

2.1. Synthesis of 2-(4-Alkylphenyl)-6-methoxyquinolines (nPQOMe, n = 4–8)

The 2-(4-Alkylphenyl)-6-methoxyquinolines were synthesized according to Scheme 1. First, the Grignard reagents 4-alkylphenylmagnesium



SCHEME 1

bromides (prepared from commercial readily available 4-alkylbromobezene) **1** were allowed to react with *N*-phenyloxycarbonyl-6-methoxyquinolinium chlorides **2** to afford a 1,2-dihydroquinolines **3**, which were then oxidized by *o*-chloranil. This is a valuable approach to synthesizing liquid crystalline 2-(4-Alkylphenyl)-6-methoxyquinolines (nPQOMe) **4**, in which the alkyl chain length was varied from *n*-butyl to *n*-octyl. The entire synthetic procedures were completed in a short two-step process. Fair to good yields (50–63%) of 2-(4-Alkylphenyl)-6-methoxyquinolines (nPQOMe, $n = 4$–8) were obtained and highly pure products were collected by continuous re-crystallization from *n*-hexane (Table 1).

It is known nucleophilic attack of a Grignard reagent and its regioselectivity on the pyridine ring can be greatly enhanced by phenyl chloroformate [21,22]. In this article, our study shows synthesis of quinoline-containing liquid crystalline compounds can also be applied with the same synthetic methodology. α-Regioselectivity of the quinoline ring by Grignard reagent attack resulting a substituent in the α-position of pyridinoid ring was found to be overwhelmingly dominant by this synthetic methodology. Trace amounts of γ-addition product can be easily separated from the major α-addition product using simple liquid chromatography (hexane: methylene choloride = 1:2) due to a high polarity difference in these two compounds.

Direct reaction of 6-methoxyquinoline with 4-pentylphenyllithium (prepared from 4-pentyliodobenzene with butyllithium) followed by refluxing under nitrobenzene has been tried by Kosaka and others [14], but their yield was lower (44.8%) compared to ours (63%). Unfortunately, mesophase of the 2-(4-pentylphenyl)-6-methoxyquinoline is not found by Kosaka and others, in contrast to what we observed, it displays enantiotropic nematic mesophase.

TABLE 1 Yields of 2-(4-Alkylphenyl)-6-methoxyquinolines (nPQOMe, $n = 4$–8)

Entry	Alkyl	Yield^a (%)
4a	Butyl	58
4b	Pentyl	60
4c	Hexyl	53
4d	Heptyl	49
4e	Octyl	47

^{a}Isolated yields are based upon after recrystalization.

2.2. Thermotropic Behavior of 2-(4-Alkylphenyl)-6-methoxyquinolines

Thermotropic behaviors of 2-(4-alkylphenyl)-6-methoxyquinoline (nPQOMe, n = 4–8) were studied by observing optical texture under a polarized optical microscope (POM) and further verified by differential scanning calorimetry (DSC) measurements. Phase transition temperatures and the corresponding transition enthalpies 2-(4-Alkylphenyl)-6-methoxyquinolines (nPQOMe, n = 4–8) are summarized in Table 2. Only the nematic phase was found in homologues of 2-aryl-6-methoxyquinolines, nPQOMe, in which n = 4, 6, and 8 are monotropic, and n = 5 and 7 are enantiotropic. It has been found for many homologous series of liquid crystals that the odd carbon atom alkyl chain has a terminal CH_3 group which extends the long molecular axis, whereas in an even number carbon chain the terminal CH_3 group tends to lie off axis [23]. Therefore, it is quite normal to find n = 5 and 7 (odd numbered carbon chains) are enantiotropic, while for n = 4, 6, and 8 (even numbered carbon chains), monotropic. The odd–even effect of the 2-aryl-6-methoxyquinolines homologues can also be manifested in the $T_{\text{I-N}}$ values shown in Table 2.

The nematic mesophase of our calamitic liquid crystals, nPQOMe, n = 4–8, generally appears in the moderately high temperature range between 65°C and 100°C, while the 2-(4-pentylphenyl)-6-methoxyquinoline, nPQOMe, n = 5, provides the widest nematic range, 3°C during heating, and 25°C during cooling. The nematic Schlieren texture of

TABLE 2 Phase Transition Temperatures (°C) and Corresponding Transition Enthalpies (kJ mol^{-1}), in Parentheses, for the Homologous Series of nPQOMe, n = 4 to 8 were Determined by the Second Scans at a Heating and Cooling Rate of 5°C min^{-1} from DSC

Entry	$T_{\text{Cr-N}}{}^{a}$ [$T_{\text{Cr-1}}$]	$T_{\text{N-I}}$	$T_{\text{I-N}}$	$T_{\text{N-Cr}}$
4a	[97.6]		86.9	79.2
(n = 4)	(12.84)		(0.09)	(11.36)
4b	96.9	100.0	98.4	73.5
(n = 5)	(21.67)	(0.24)	(0.36)	(20.5)
4c	[92.0]		83.6	67.9
(n = 6)'	(21.88)		(0.20)	(21.61)
4d	94.0	96.2	94.8	79.2
(n = 7)	(15.90)	(0.16)	(0.25)	(15.9)
4e	[88.5]		85.8	69.0
(n = 8)	(23.86)		(0.27)	(24.50)

[a] Cr = crystalline phase, *N* = nematic phase, *I* = isotropic phase.

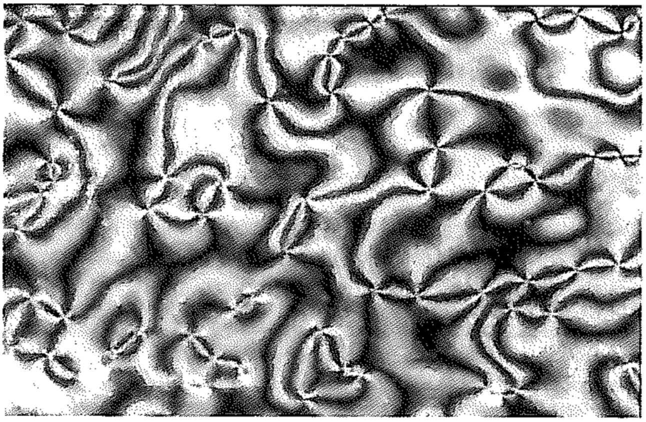


FIGURE 1 Polarized optical micrograph of nematic Schlieren texture of 2-(4-butylphenyl)-6-methoxyquinoline **(4a) nPQOMe, n = 4** arises from isotropic phase on cooling to 86°C with magnification of ×100.

2-(4-butylphenyl)-6-methoxyquinoline (**4a**) nPQOMe, n = 4 arises from isotropic phase on cooling to 86°C is shown in Fig. 1, and its corresponding second scan thermogram is shown in Fig. 2. Furthermore,

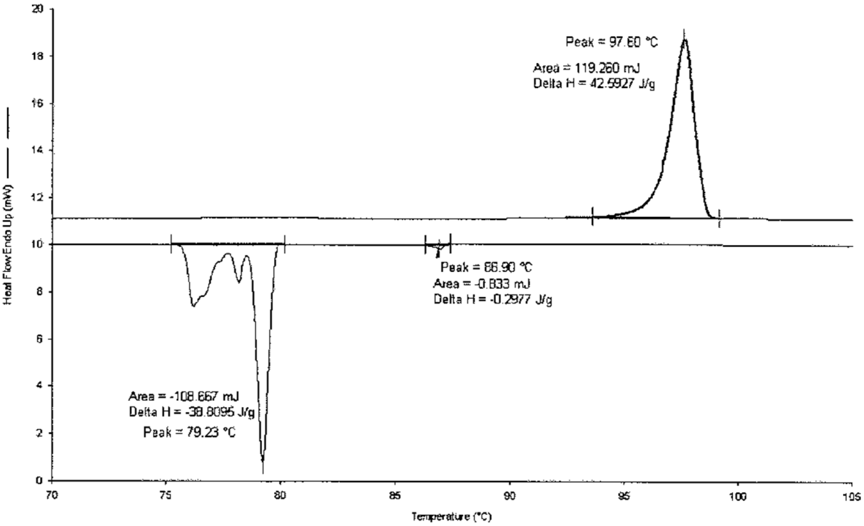


FIGURE 2 Thermogram of 2-(4-butylphenyl)-6-methoxyquinoline, nPQOMe, n = 4, were determined by the second scans at a heating and cooling rate of 5°C min^{-1} from DSC.

in a thick sample under pom we could not observe the broken focal conic structure, which is a characteristic phenomenon of smectic C phase.

Although several 2-arylquinolines liquid crystalline analogues were examined previously [3], disappointingly (except the one reported by Kosaka *et al.* [14]), those 2-arylquinolines showed no methoxy substituents at the 6-position of quinoline, and therefore, are different from those currently being examined. For example, 2-(4-butylphenyl)-6-butoxyquinoline (4-PQ-O4) was found to have a nematic mesophase between 77°C to 112°C; 2-(*p*-ethylphenyl)-6-ethoxyquinoline (2-PQ-O2) melted to be isotropic liquid at 139°C and has a monotropic nematic phase transition observed at 109°C [3]. Similar quinoline-containing liquid crystalline homologues of 6-Alkyl-2-(4-alkyloxyphenyl)quinoline (nO-PQ-m, $n = 5$–10, $m = 5$–8) has been reported, in which with longer tails on both ends of the phenylquinoline core exhibit to be a smectic C base material [4]. Mesomorphic properties of 2-phenylnaphthalenes may also be compared with those of 2-phenylquinolines. For example, 6-(4-hexylphenyl)-2-methoxynaphthalene (6-PNP-OMe) has a nematic phase between 113°C to 122°C [24], which indicates that the nematic stability of phenylnaphthalene core (PNP) is higher than that of phenylquinoline core (PQ). With longer alkyl chains on both ends of 2,6-disubstituted phenylnaphthalene core, 2-(4-octylphenyl)-6-butylnaphthalene (8-PNP-4) displays only smectic phases (Cryst. −3.5 SmE 75.2 SmB 88.8 SmA 93.0 Iso. Unit:°C) [25]. In order to reach nematic mesophase in ambient temperature as well as with an appropriate and extended range, we believe that more researches have to be conducted for either short chain ends and/or unsymmetric chain ends on both sides of the suitable liquid crystalline core structures.

3. EXPERIMENTAL

All chemicals and solvents were of reagent grade from Aldrich Chemical Co. Anhydrous solvents and chemicals were freshly distilled before use. The ^{1}H and ^{13}C-NMR spectrums were recorded on a Brucker AC 300 spectrometer. Infrared spectrums were recorded using a Perkin-Elmer 1600 Series spectrometer.

Thermographs were carried out on a Perkin-Elmer DSC 7 Series, calibrated with pure indium. Polarizing optical microscopy was carried out on an Olympus BH-2 research microscope equipped with a Mettler FP90/FP82HT hot stage. All phase transitions were measured with a scan rate of $5°\mathrm{C\,min^{-1}}$.

3.1. General Procedure for the Synthesis of 2-(4-Alkylphenyl)-6-methoxyquinolines (nPQOMe, n = 4–8)

For **3a:** To a (Grignard) solution of 1-bromo-4-butylbenzene (10 mmol) in THF (20 ml) was added freshly dried magnesium granules (11 mmol) under an inert atmosphere. The Grignard solution **1** was then slowly added by syringe into a preformed solution of 6-methoxyquinolinium chloride **2**, which was prepared from phenyl chloroformate (10 mmol), 6-methoxyquinoline (10 mmol) in dry THF (20 ml) under −20°C for half an hour. The resulting solution was heated slowly to room temperature and stirred for another 8 hours. After evaporating the THF, the residue was extracted with Et_2O. The organic layer was further washed once with 20% NH_4Cl solution and twice with distilled water and brine, and dried with magnesium sulfate. The intermediate **3a** was then used for the next oxidation step without further purification. For **4a:** To a solution of dry toluene (20 ml) and crude **3a** was added about 1.5eq. *o*-chloranil. The reaction mixture was heated to reflux for about three hours under inert atmosphere and then quenched by adding 1N NaOH (25 ml) and Et_2O (25 ml) and filtered through Celite. Normal aqueous work up and isolation with column chromatography (hexane: methylene choloride = 1:2) afford 2-(4-butylphenyl)-6-methoxyquinoline (**4a**). The fairly good yield (58%) of product **4a** was obtained by re-crystallization several times from *n*-hexane. The yield was based upon the overall two-step reaction. All compounds gave satisfactory data from ^{1}H-NMR, ^{13}C-NMR, IR, and elemental analysis as illustrated below.

3.1.1. *2-(4-Butylphenyl)-6-methoxyquinoline (nPQOMe, n = 4) (4a)*

^{1}H-NMR ($CDCl_3$): δ 8.00–8.11 (m, 4H), 7.80 (d, 1H, $J = 8.4$ Hz), 7.36 (dd, 1 H, $J_1 = 9.3$ Hz, $J_2 = 3$ Hz), 7.31 (d, 2 H, $J = 8.1$ Hz), 7.06 (d, 1 H, $J = 2.7$ Hz), 3.93 (s, 3 H), 2.67 (t, 2 H, $J = 7.5$ Hz), 1.72–1.58 (m, 2 H), 1.47–1.30 (m, 2 H), 0.94 (t, 3 H, $J = 7.5$ Hz). ^{13}C-NMR ($CDCl_3$): ppm 157.6, 155.2, 144.4, 144.0, 137.3, 135.4, 131.1, 129.0, 128.0, 127.2, 122.2, 119.2, 119.2, 105.1, 55.6, 35.5, 22.4, 14.0. IR (KBr): cm^{-1} 3061, 2959, 2928, 2855, 1599, 1495, 1252, 1022, 835. Anal. Calcd for $C_{20}H_{21}NO$: C, 82.44; H 7.26; N 4.81, Found: C, 82.00; H, 7.25; N, 4.72.

3.1.2. *2-(4-Pentylphenyl)-6-methoxyquinoline (nPQOMe, n = 5) (4b)*

^{1}H-NMR ($CDCl_3$): δ 8.29–8 00 (m, 4 H), 7.80 (d, 1 H, $J = 8.4$ Hz), 7.36 (dd, 1 H, $J_1 = 9$ Hz, $J_2 = 2.7$ Hz), 7.31 (d, 2 H, $J = 8.4$ Hz), 7.05 (d, 1 H,

$J = 3$ Hz), 3.93 (s, 3 H), 2.67 (t, 2 H, $J = 7.2$ Hz), 1.76–1.57 (m, 2 H), 1.38 ~ 1.29 (m, 4 H), 0.89 (t, 3 H, $J = 6.6$ Hz). ^{13}C-NMR ($CDCl_3$): ppm 157.5, 155.2, 144.4, 144.0, 137.2, 135.4, 131.1, 128.9, 128.0, 127.2, 122.2, 119.2, 105.1, 55.5, 35.7, 31.5, 31.1, 22.6, 14.1. IR (KBr): cm^{-1} 3062, 2957, 2920, 2855, 1600, 1495, 1250, 1027, 833. Anal. Calcd for $C_{21}H_{23}NO$: C, 82.58; H 7.59; N 4.59, Found: C, 82.36; H, 7.55, N, 4.52.

3.1.3. *2-(4-Hexylphenyl)-6-methoxyquinoline (nPQOMe, n = 6) (4c)*

^{1}H-NMR ($CDCl_3$): δ 8.13–8.00 (m, 4 H), 7.81 (d, 1 H, $J = 8.7$ Hz), 7.37 (dd, 1 H, $J_1 = 9.3$ Hz, $J_2 = 3$ Hz), 7.32 (d, 2 H, $J = 8.1$ Hz), 7.08 (d, 1 H, $J = 2.7$ Hz), 3.93 (s, 3 H), 2.67 (t, 2 H, $J = 7.5$ Hz), 1.72–1.58 (m, 2 H), 1.45–1.19 (m, 6 H), 0.98–0.82 (m, 3 H). ^{13}C-NMR ($CDCl_3$): ppm 157.6, 155.2, 144.4, 144.0, 137.3, 135.4, 131.2, 129.0, 128.0, 127.2, 122.2, 119.2, 105.1, 55.6, 35.8, 31.8, 31.4, 29.0, 22.7, 14.1. IR (KBr): cm^{-1} 3061, 2957, 2920, 2853, 1599, 1495, 1252, 1028, 831. Anal. Calcd for $C_{22}H_{25}NO$: C, 82.72; H 7.89; N 4.38, Found; C, 82.41; H, 7.88; N, 4.32.

3.1.4. *2-(4-Heptylphenyl)-6-methoxyquinoline (nPQOMe, n = 7) (4d)*

^{1}H-NMR ($CDCl_3$): δ 8.13 –; 8.00 (m, 4 H), 7.81 (d, 1 H, $J = 8.4$ Hz), 7.37 (dd, 1 H, $J_1 = 9.3$ Hz, $J_2 = 3$ Hz), 7.31 (d, 2 H, $J = 8.1$ Hz), 7.08 (d, 1 H, $J = 3$ Hz), 3.94 (s, 3 H), 2.67 (t, 2 H, $J = 7.5$ Hz), 1.74 – 1.57 (m, 2 H), 1.40 – 1.20 (m, 8 H), 0.88 (t, 3 H, $J = 7.2$ Hz). ^{13}C-NMR ($CDCl_3$): ppm 157.6, 155.2, 144.4, 144.1, 137.3, 135.4, 131.2, 128 9, 128.0, 127.2, 122.2, 119.2, 105.1, 55.6, 35.8, 31.9, 31.4, 29.3, 29.2, 22.7, 14.1. IR (KBr): cm^{-1} 3061, 2958, 2922, 2853, 1599, 1495, 1252, 1022, 833. Anal. Calcd for $C_{23}H_{27}NO$: C, 82.84; H 8.16; N 4.20, Found: C, 82.52; H, 8.08; N, 4.18.

3.1.5. *2-(4-Octylphenyl)-6-methoxyquinoline (nPQOMe, n = 8) (4e)*

^{1}H-NMR ($CDCl_3$): δ 8.13 – 8.00 (m, 4 H), 7.81 (d, 1 H, $J = 8.7$ Hz), 7.36 (dd, 1 H, $J_1 = 9.3$ Hz, $J_2 = 3$ Hz), 7.31 (d, 2 H, $J = 8.1$ Hz), 7.08 (d, 1 H, $J = 3.0$ Hz), 3.94 (s, 3 H), 2.67 (t, 2 H, $J = 7.5$ Hz), 1.75–1.58 (m, 2 H), 1.42–1.19 (m, 10 H), 0.88 (t, 3 H, $J = 7.2$ Hz). ^{13}C-NMR ($CDCl_3$): ppm 157.6, 155.2, 144.4, 144.1, 137.3, 135.4, 131.2, 128.9, 128.0, 127.2, 122.2, 119.2, 105.1, 55.6, 35.8, 31.9, 31.5, 29.6, 29.3, 22.7, 14.1. IR (KBr): cm^{-1} 3063, 2957, 2919, 2849, 1599, 1497, 1250, 1028, 833. Anal. Calcd for $C_{24}H_{29}NO$: C, 82.95; H 8.41; N 4.03, Found: C, 82.82; H, 8.33; N, 3.84.

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