Synthesis and mesophase behaviour of Benzylidene-based molecules containing two Azomethine units

Z Jamain and M Khairuddin

1 Faculty of Science and Natural Resources, Universiti Malaysia Sabah (UMS), 88400 Kota Kinabalu, Sabah, Malaysia
2 School of Chemical Sciences, Universiti Sains Malaysia (USM), 11800 USM Penang, Malaysia

E-mail: zuhairjamain@ums.edu.my

Abstract. The research work involves the synthesis and characterization of intermediates 4-heptyloxybenzaldehyde (1) and 4-dodecylloxybenzaldehyde (2). Five compounds with two Schiff base linking units were further synthesized by condensation reaction using aldehyde and 1,4-phenylenediamine. These compounds include N,N'-dibenzyliden-benzen-1,4-diamine (3); N-benzyliden-N’-(4-chlorobenzyliden)benzen-1,4-diamine (4); N-benzyliden-N’-(4-methoxybenzyliden)benzen-1,4-diamine (5); N-benzyliden-N’-(4-heptyloxybenzyliden)benzen-1,4-diamine (6) and N-benzyliden-N’-(4-dodecylloxybenzyliden)benzen-1,4-diamine (7). These compounds were characterized using Fourier-Transform Infrared (FTIR), $^1$H and $^{13}$C Nuclear Magnetic Resonance (NMR) spectroscopy and CHN elemental analysis. Polarized Optical Microscope (POM) was used to detect liquid crystal mesophase(s) and their thermal behaviour was measured using Differential Scanning Calorimetry (DSC). Compounds 4, 6 and 7 showed the nematic phases, while compounds 3 and 5 were found to be non-mesogenic without any liquid crystal properties.

1. Introduction

Liquid crystals (LCs) is a state of matter between solid (crystal) and liquid (isotropic) states. The study of LCs behaviour started in 1888 with the discovery of two distinct melting points for cholesteryl benzoate material by Austrian botanist, Friedrich Reinitzer [1]. During heating process, this crystal changes into a hazy liquid and further heating makes this hazy liquid transformed into a clear, transparent liquid. This finding caused the researcher began to discover a new phase of matter which is called as liquid crystals phase [2].

Molecules with LC properties are called mesogen and their LC phase transitions exist as mesophase(s). There are two types of LC for organic compounds, which are thermotropic and lyotropic LCs [3]. Thermotropic LCs are temperature dependent while lyotropic LCs are temperature and solvent dependent. The thermotropic LCs are divided into the calamitic (rod-like) and discotic (disc-like) [3]. Calamitic is a rod-shaped molecule and usually exhibits the properties of nematic and smectic phase LC [4]. A nematic phase has no positional order and tends to point in the same direction. On the other hand, a smectic phase shows a slight degree of translational order in molecules [5]. This causes the smectic phase to be more solid-like than the nematic [6].

In general, the skeleton structures influence the mesophase texture of the compounds. The molecules with the structure of a rod-like shaped usually consists of a core (ring system) which is...
connected to other core system by linking units. Such molecules will have a series of different terminal groups (Figure 1).

![Diagram](https://example.com/diagram.png)

**Figure 1.** Common rod-like LC structure.

The research works involved the preparation of thermotropic rod-like liquid crystal molecule. The research was conducted in order to understand the relationship of the skeleton structure of molecules in relation to the liquid crystal behaviour. The research has chosen a series of molecules comprise of an aromatic ring core attached to another core by two Schiff base linking units. Schiff base contains carbon double bond with nitrogen atom connected to an alkyl or aryl group but not the hydrogen [7]. These Schiff base molecules provide a stepped core structure, which can maintain the molecular linearity. This linearity will provide high stability and enabling mesophase formation [8]. Schiff base are very useful in liquid crystal research due to low temperature of phase transitions [9].

2. Results and Discussion

The preparation of the 4-alkoxybenzaldehyde (1 and 2) via the alkylation of 4-hydroxybenzaldehyde with alkyl bromide are shown in Scheme 1. Compounds 1 and 2 with other commercially available benzaldehydes such as benzaldehyde, 4-chlorobenzaldehyde, and 4-methoxybenzaldehyde was then reacted with 1,4-phenylenediamine to produce compounds 3-7 with two Schiff base linking units (Scheme 2).

![Scheme 1](https://example.com/scheme1.png)

**Scheme 1.** Alkylation reaction of compounds 1 and 2 [10].

![Scheme 2](https://example.com/scheme2.png)

**Scheme 2.** Condensation reaction of compounds 3-7 [11, 12].
2.1. FTIR Spectral Discussion
The IR spectra of intermediates 1 and 2 showed aldehydeic C-H stretching at ~2730.0 cm⁻¹, C=O stretching at 1689.2 cm⁻¹, C=C stretching at 1602.0 cm⁻¹ and C-O stretching at 1253 cm⁻¹. The disappearance of broad absorption band at ~3300.0 cm⁻¹ for the O-H group confirming the successful of the insertion of the alkyl groups. The IR spectra for compounds 3-7 (Figure 2) showed similar absorption bands with the C=N stretching at ~1600.0 cm⁻¹, C=C stretching at ~1500.0 cm⁻¹ and C-N stretching at ~1160.0 cm⁻¹. Other absorption bands observed was the C-Cl stretching (824.4 cm⁻¹) in compound 4, C=O stretching (1249.5 cm⁻¹) in compounds 5, 6 and 7 and strong C-H (sp³) stretching (2850-2980 cm⁻¹) in compounds 6 and 7. The aldehydic C-H stretching was not appeared in compounds 3-7 but instead all these compounds showed the azomethine (C=N) stretching which confirmed that the condensation reaction was a success.

![FTIR spectra overlay for compounds 3-7](image)

Figure 2. The FTIR spectra overlay for compounds 3-7

2.2. NMR Spectral Discussion
The ¹H NMR of intermediates 1 and 2 revealed the same pattern of protons. Intermediates 1 and 2 showed one carbonyl proton at δ_H 9.83 and 9.87 ppm, respectively. There were two doublets of the aromatic protons at δ_H 7.00, 7.81 ppm and 7.02, 7.80 ppm, respectively. The aliphatic protons were observed in the upfield region for 15 protons from δ_H 0.83 to 3.95 ppm and 25 protons from δ_H 0.80 to 3.98 ppm, respectively. The ¹³C NMR for 1 and 2 showed 12 and 17 carbon signals, respectively.

The ¹H NMR of the symmetrical compound 3 showed the most deshielded singlet at 8.69 ppm for the azomethine proton. The aromatic protons appeared as singlet at δ_H 7.37 ppm, doublet at δ_H 7.96 ppm and multiplet at δ_H 7.54-7.53 ppm. For the unsymmetrical compound 4, there were two different azomethine protons at δ_H 8.69 and δ_H 8.71 ppm. The aromatic protons were assigned for signals at δ_H
7.97, 7.60, 7.37 and 7.54-7.53 ppm. The ¹H NMR of compound 5, compound 6, and compound 7 showed similar pattern as compound 4 with an additional methyl proton at δH 3.90 in compound 5, 15 aliphatic protons from δH 0.89 to 4.07 ppm in compound 6, and 25 aliphatic protons from δH 0.87 to 4.07 ppm in compound 7.

The ¹³C NMR was used to verify the molecular structure of compounds 3-7. The peak in the region of δC 160 ppm was due to the azomethine carbon. Compounds 3-5 showed similar patterns with a methyl carbon at δC 55.78 ppm in compound 5. Compounds 6 and 7 showed the aliphatic carbons in the upfield regions, which were assigned to 7 and 12 carbons, respectively.

2.3. Determination of Mesophase Behaviour

The LCs behaviour for compounds 3-7 were determined using polarized optical microscope (POM). Compounds 4, 6 and 7 were found to exhibit liquid crystal properties (mesogenic) but no liquid crystal properties were observed for compounds 3 and 5 (non-mesogenic).

Compounds 3 and 5 were found to be non-mesogenic with the transitions of crystal to isotropic. No liquid crystal phases were observed in both heating and cooling cycles. Compound 4 was found to exhibit nematic phase at 164.9°C before it became isotropic at 174.0°C in the heating cycle. During cooling cycle, the nematic phase appeared at 163.9°C and became crystal phase at 151.8°C. Meanwhile, compound 6 exhibited a nematic phase at 117.2°C and became isotropic at 211.1°C during heating. The nematic phase was observed at 209.6°C and turned into crystal at 117.6°C upon cooling. Besides, compound 7 exhibited a nematic phase at 129.5°C and became isotropic at 210.2°C during heating. Upon cooling, the nematic phase appeared at 208.4°C and became crystal at 120.8°C. The nematic texture of compounds 4, 6 and 7 are illustrated in Figures 3-5, respectively.

2.4. Determination of Thermal Behaviour

Mesophase transition of compounds 4, 6 and 7 were further confirmed their thermal behaviour using differential scanning calorimetry (DSC). The experiment involves the heating and cooling of the compounds. These data are summarized in table 1 and 2.
Table 1. DSC thermal transitions of compounds 4, 6 and 7 (Heating cycle).

| Compounds | Transition temperatures (ºC) | Enthalpy (ΔH = kJ mol⁻¹) |
|-----------|-----------------------------|--------------------------|
|           | Cr₁ | Cr₂  | N   | I   |
| 4         | •   | 165.53 (5.22) | •   | 170.85 (26.67) | • |
| 6         | •   | 115.57 (32.10) | •   | 209.98 (1.34)  | • |
| 7         | •   | 96.78 (1.42)  | •   | 130.67 (1.73)  | 210.65 (1.02) |

Note: Cr = Crystal, N = Nematic, I = Isotropic.

Table 2. DSC thermal transitions of compounds 4, 6 and 7 (Cooling cycle).

| Compounds | Transition temperatures (ºC) | Enthalpy (ΔH = kJ mol⁻¹) |
|-----------|-----------------------------|--------------------------|
|           | I   | N   | Cr₁ | Cr₂ |
| 4         | •   | 160.78 (22.61) | •   | 152.39 (4.75)  | • |
| 6         | •   | 207.78 (1.32)  | •   | 122.62 (3.90)  | • |
| 7         | •   | 208.77 (0.90)  | •   | 124.28 (1.54)  | 86.13 (0.87)  |

Note: Cr = Crystal, N = Nematic, I = Isotropic.

In the DSC thermogram (heating cycle), compound 4 showed a curve with a shoulder at the region of 167.28-172.29 ºC. This confirmed the POM observation of a quick nematic phase before it turned into isotropic phase. In the cooling cycle of compound 4, the isotropic transform into a quick transition of the nematic phase before it changed into crystal phase. The DSC thermogram for compounds 6 and 7 in the heating and cooling cycles showed similar pattern of the mesophase transitions as observed in POM.

2.5. Structure Property Relationship

In general, the liquid crystal properties of the molecules were influenced by the arrangement and skeleton structures in the compound. A molecule must fulfil certain requirement to enhance the liquid crystal mesophase. The physical properties of even the simplest liquid crystal compound are truly remarkable due to the self-assembly of molecules. The self-assembly can occurred in an ordered, yet fluid, liquid crystal mesophase [13]. Rod-shaped molecules have an elongated, anisotropic geometry which are maintained through the rigidity and linearity of its constituents. Two interconnected cyclic rings cause the resulting compound to have a linear planar conformation [14]. The main criteria for a molecule to adopt liquid crystal behaviour include the molecular shape which should be relatively thin or flat within rigid molecular frameworks, which usually based on benzene rings [15]. The structure should not be branched or angular (bilateral substitution) which might disrupt the linearity of the molecule.

A linking unit between ring systems is to increase the length of the molecules, as well as to alter the polarizability and flexibility of the molecules [16]. In liquid crystal molecules, linking unit connects one core to another and is also used to link the terminal chain to the core. Schiff base offer the possibility of controlling the alignment and orientation of their molecules which can generate liquid crystal materials [17]. As a result, compounds 4, 6 and 7 with two Schiff base linking units exhibited the nematic phase. The existence of polar chlorine substituents with strong dipole moments (compound 4) enhance the stability of lattice and melting temperatures, thus having the ability to
promote mesomorphic properties [18]. The polar group is more likely to produce a nematic phase than a methyl group or a hydrogen atom [19].

Alkyl and alkoxy side chain length has also been demonstrated to have a dramatic effect on mesophase formation. Compounds with long terminal chain length usually will exhibit enantiotropic mesophase, which is thermodynamically stable. However, compounds with shorter alkyl chains showed the monotropic mesophase, which has unstable behaviour [20]. This was proven when compounds 3 and 5 did not show any liquid crystal phase. The nature of the longer terminal substituents or end groups in the molecule of the mesogen has profound influence on the liquid crystal properties of the compound [21]. Compounds 6 and 7 with heptyl and dodecyl terminal chains, respectively, also showed the nematic phase in both cycles. This behaviour was due to the long alkyl chains add flexibility to the rigid core and stabilize the molecular interactions needed for the formation of liquid crystal mesophase [12, 22].

3. Materials and Methods

3.1. Chemicals

The chemicals that were used for in this research are 4-hydroxybenzaldehyde, benzaldehyde, 1,4-phenyldiamine, 4-chlorobenzaldehyde, 4-methoxybenzaldehyde, methanol, 1-bromododecane, 1-bromoheptane, \(N,N\)-dimethylformamide, potassium carbonate, sodium sulphate anhydrous, ethyl acetate. All chemicals were purchased from Merck, Sigma-Aldrich, Fluka, and Qroc (Asia). These chemicals and solvents were used as received without further purifications.

3.2. Synthesis Method

3.2.1. Synthesis of 4-heptoxybenzaldehyde, 1

4-Hydroxybenzaldehyde (0.10 mol) was dissolved in 20 mL of \(N,N\)-dimethylformamide, DMF and another 20 mL of DMF were used to dissolve 1-bromoheptane (0.10 mol), separately. Both solutions were mixed in a 250 mL round bottom flask. Potassium carbonate (0.12 mol) and potassium iodide (0.01 mol) were added into the mixture and refluxed for 12 hours. The reaction was monitored using TLC. Upon completion, the mixture was poured into 500 mL of cold water, filtered, washed with cold water and dried in vacuum overnight. The same procedure was used to synthesize compound 2. Yield: 14.37 g (65.3%), light-yellow oil. FTIR (cm\(^{-1}\)): 3080.7 (C=O stretching), 2928.1 and 2859.1 (C-H stretching), 2735.6 (H-CO, aldehydeic), 1689.2 (C=O stretching), 1602.0 (C=C stretching), 1253.1 (C-O stretching). \(^1\)H-NMR (500 MHz, DMSO-\(d_6\)). \(\delta\), ppm: 9.87 (s, 1H), 7.81 (d, \(J = 8.5\) Hz, 2H), 7.00 (d, \(J = 9.0\) Hz, 2H), 3.95 (t, \(J = 6.5\) Hz, 2H), 1.67-1.70 (m, 2H), 1.34-1.35 (m, 2H), 1.21-1.27 (m, 6H), 0.83 (t, \(J = 7.0\) Hz, 3H). \(^1\)C-NMR (125 MHz, DMSO-\(d_6\)) \(\delta\), ppm: 190.12, 163.60, 131.43, 129.53, 114.41, 67.86, 35.37, 31.34, 28.55, 25.44, 22.10, 13.66.

4-Dodecylxybenzaldehyde, 2; Yield: 22.88 g (78.90%), dark-yellow oil. FTIR (cm\(^{-1}\)): 3073.5 (C=O-H stretching), 2924.5 and 2855.5 (C\(sp^2\)-H stretching), 2732.0 (H-CO, aldehydic), 1689.2 (C=O stretching), 1602.0 (C=C stretching), 1253.1 (C-O stretching). \(^1\)H-NMR (500 MHz, DMSO-\(d_6\)). \(\delta\), ppm: 9.83 (s, 1H), 7.80 (d, \(J = 8.5\) Hz, 2H), 7.02 (d, \(J = 9\) Hz, 2H), 3.98 (t, \(J = 6.3\) Hz, 2H), 1.66-1.67 (m, 2H), 1.34-1.35 (m, 2H), 1.12-1.28 (m, 16H), 0.80 (t, \(J = 6.8\) Hz, 3H). \(^1\)C-NMR (125 MHz, DMSO-\(d_6\)) \(\delta\), ppm: 190.76, 163.58, 131.38, 129.50, 127.71, 67.74, 31.27, 29.08, 28.68, 25.49, 22.23, 13.74.

3.2.2. Synthesis of \(N,N\)'-Dibenzyliden-benzen-1,4-diamine, 3

A mixture of benzaldehyde (4.70 mmol) and 1,4-phenyldiamine (2.24 mmol) were added in methanol (15 mL) in a round bottom flask. The reaction was stirred at room temperature for two hours. The reaction was monitored by TLC. Upon completion, the mixture was cooled in ice and the precipitate formed was filtered and dried. The crude was recrystallized using methanol. The same method was used to synthesize compounds 4-7. Yield = 0.57 g (89.55%), mp: 129.5-133.1 °C, yellow powder. FTIR (cm\(^{-1}\)): 3055.3 and 3029.9 (C\(sp^2\)-H stretching), 1616.5 (C=N stretching), 1493.0 (C=C

\(5\)
stretched), 1191.4 (C-N stretching). $^1$H NMR (500 MHz, DMSO-d$_6$), $\delta$(H ppm): 8.69 (s, 1H), 7.96 (d, $J = 8$ Hz, 2H), 7.54-7.53 (m, 3H), 7.37 (s, 2H). $^{13}$C NMR (125 MHz, DMSO-d$_6$), $\delta$(C ppm): 160.06, 149.28, 136.06, 131.42, 128.73, 122.01. Calculated for C$_{20}$H$_{16}$N$_2$: C: 84.51%, H: 5.63% N: 9.86%; Found: C: 85.97% H: 5.65% N: 9.98%.

N-Benzyliden-N’-(4-chlorobenzylidene)benzen-1,4-diamine, 4; Yield = 1.19 g (79.29%), mp: 176.9-181.7 °C, yellow powder. FTIR (cm$^{-1}$): 3062.6 and 3029.9 (Csp$^2$-H stretching), 1612.9 (C=C stretching), 1489.3 (C=C stretching), 1187.7 (C-N stretching) 824.4 (C-Cl stretching). $^1$H NMR (500 MHz, DMSO-d$_6$), $\delta$(H ppm): 8.71 (s, 1H), 8.69 (s, 1H), 7.97 (d, $J = 8$ Hz, 4H), 7.60 (d, $J = 8.5$ Hz, 2H), 7.54-7.53 (m, 3H), 7.37 (d, $J = 2.5$ Hz, 4H). $^{13}$C NMR (125 MHz, DMSO-d$_6$), $\delta$(C ppm): 160.16, 160.05, 158.83, 149.20, 136.00, 134.93, 131.44, 131.41, 130.23, 128.95, 128.81, 128.64, 122.02, 122.00. Calculated for C$_{20}$H$_{13}$N$_2$Cl: C: 75.37%, H: 4.71% N: 8.79%; Found: C: 75.70% H: 4.54% N: 8.76%.

N-Benzyliden-N’-(4-methoxybenzyliden)benzen-1,4-diamine, 5; Yield = 0.96 g (65.11%), mp: 124.7-129.9 °C, yellow powder. FTIR (cm$^{-1}$): 3059.0 and 3033.5 (Csp$^2$-H stretching), 2942.7 (Csp$^2$-H stretching), 1616.5 (C=C stretching), 1482.0 (C=C stretching), 1249.5 (C-O stretching), 1187.7 (C-N stretching). $^1$H NMR (500 MHz, DMSO-d$_6$), $\delta$(C ppm): 160.16, 159.24, 154.80 (ppm): 8.90 (s, 1H), 8.69 (s, 1H), 8.04-8.0 (m, 1H), 7.95-7.96 (m, 2H), 7.54 (d, $J = 1.5$ Hz, 2H), 7.53 (d, $J = 2.5$ Hz, 2H), 7.36 (d, $J = 11$ Hz, 2H), 7.30 (d, $J = 10.5$ Hz, 2H), 7.11 (d, $J = 11.75$ Hz, 2H), 3.91 (t, $J = 10$ Hz, 3H). $^{13}$C NMR (125 MHz, DMSO-d$_6$), $\delta$(C ppm): 160.06, 159.24, 154.80, 149.82, 149.28, 149.28, 136.06, 133.13, 131.42, 128.81, 126.76, 123.88, 122.01, 120.66, 112.01, 55.78. Calculated for C$_{21}$H$_{18}$N$_2$O: C: 80.25%, H: 5.73% N: 8.91%; Found: C: 80.14% H: 5.71% N: 8.83%.

N-Benzyliden-N’-(4-heptyloxybenzyliden)benzen-1,4-diamine, 6; Yield = 1.37 g (76.22%), mp: 214.6-220.7 °C, yellow powder. FTIR (cm$^{-1}$): 3062.6 (Csp$^2$-H stretching), 2924.5 and 2855.5 (Csp$^2$-H stretching), 1605.6 (C=C stretching), 1507.5 (C=C stretching), 1249.5 (C-O stretching), 1166.0 (C-N stretching). $^1$H NMR (500 MHz, DMSO-d$_6$), $\delta$(H ppm): 8.68 (s, 1H), 8.58 (s, 1H), 7.96 (d, $J = 2$ Hz, 2H), 7.95 (d, $J = 4$ Hz, 2H), 7.87-7.89 (m, 3H), 7.34 (d, $J = 8.5$ Hz, 2H), 7.30 (d, $J = 8.5$ Hz, 2H), 7.06 (d, $J = 8.5$ Hz, 2H), 4.07 (t, $J = 6.5$ Hz, 2H), 1.74-1.77 (m, 2H), 1.43-1.45 (m, 2H), 1.31-1.36 (m, 6H), 0.89 (t, $J = 6.8$ Hz, 3H). $^{13}$C NMR (125 MHz, DMSO-d$_6$), $\delta$(C ppm): 160.05, 159.55, 131.72, 130.86, 129.55, 129.21, 129.05, 122.36, 122.24, 115.35, 68.43, 31.62, 29.10, 28.79, 25.88, 22.40, 14.24. Calculated for C$_{27}$H$_{18}$N$_2$O: C: 84.82%, H: 7.85% N: 7.33%; Found: C: 83.49% H: 7.99% N: 6.98%.

N-Benzyliden-N’-(4-dodecylxybenzyliden)benzen-1,4-diamine, 7; Yield = 1.79 g (84.05%), mp: 166.5-171.2 °C, yellow powder. FTIR (cm$^{-1}$): 3062.6 (Csp$^2$-H stretching), 2917.2 and 2848.2 (Csp$^2$-H stretching), 1605.6 (C=C stretching), 1507.5 (C=C stretching), 1249.5 (C-O stretching), 1169.6 (C-N stretching). $^1$H NMR (500 MHz, DMSO-d$_6$), $\delta$(H ppm): 8.68 (s, 1H), 8.58 (s, 1H), (d, $J = 3.5$ Hz, 2H), 7.88 (d, $J = 8$ Hz, 2H), 7.52-7.53 (m, 3H), 7.34 (d, $J = 8.5$ Hz, 2H), 7.30 (d, $J = 6$ Hz, 2H), 7.06 (d, $J = 8.5$ Hz, 2H), 4.07 (t, $J = 6.3$ Hz, 2H), 1.74-1.75 (m, 2H), 1.43-1.44 (m, 2H), 1.10-1.27 (m, 16H), 0.87 (t, $J = 6.3$ Hz, 3H). $^{13}$C NMR (125 MHz, DMSO-d$_6$), $\delta$(C ppm): 161.95, 160.05, 159.54, 150.31, 149.43, 136.78, 131.72, 130.86, 129.55, 129.21, 129.05, 122.34, 122.24, 115.34, 68.41, 31.69, 29.35, 29.12, 29.06, 25.88, 22.44, 14.24. Calculated for C$_{32}$H$_{20}$N$_2$O: C: 84.96%, H: 8.85% N: 6.19%; Found: C: 83.75% H: 8.96% N: 5.89%.

Conclusion
Two intermediates, 1 and 2 and a series of azomethine compounds 3-7 were successfully synthesized and their structural elucidation were characterized using FTIR, $^1$H and $^{13}$C NMR spectroscopy and CHN elemental analysis. Determination of the liquid crystal behaviour for these compounds using POM showed that compounds 4, 6 and 7 are mesogenic with nematic phase of a thread-like texture.
However, compounds 3 and 5 were found to be non-mesogenic without any liquid crystal properties. The thermal transitions for all the liquid crystal mesophase observed in the DSC thermogram confirmed the existence of the nematic phase in these compounds.

Acknowledgments
The authors would like to thank Universiti Malaysia Sabah for the research funding with grant number of SGA0037-2019 and SPB0004-2020; and Universiti Sains Malaysia with grant number of 1001/PKIMIA/811332.

Conflict of Interest
The authors declare no conflict of interest.

References
[1] Andrienko D 2018 J. Mol. Liq. 267 520–541
[2] Kim C and Allcock H R 1987 Macromolecules 20 1726–1727
[3] Singh S and Dunmur D 2002 Liquid crystals: Fundamentals (World Scientific) pp. 1–3
[4] Collings P J and Hird M 1997 Introduction to Liquid Crystal: Chemistry and Physic (London Taylor & Francis, MIT Press)
[5] Collings P J 2002 Liquid Crystals: Nature's Delicate Phase of Matter (New Jersey: Princeton Univ. Press) p. 204
[6] Shenderovskyi V A, Trokhymchuk A D, Lisetski L N, Kozhushko B V, Gvozdovskyy I A 2018 J. Mol. Liq. 267 560–563
[7] Raghuwanshi P B and Malalle P V 2014 Pharma Chemica 6 262-266
[8] Jamain Z, Khairuddean M, Zulbaharen N N and Chung T K 2019 Malays. J. Chem. 21 73–85
[9] Thaker B T, Kanojiya J B and Tandel R S 2010 Mol. Cryst. Liq. Cryst. 528 120
[10] Pradsad K R and Kumar J V S 2011 Res. J. Chem. Sci. 1 89–91
[11] Beyramabadi S A, Saadat-Far M, Faraji-Shovey A, Javan-Khoshkholgh M and Morsali A 2020 J. Mol. Struct. 1208 127898
[12] Jamain Z, Omar N F and Khairuddean M 2020 Molecules 25 3780
[13] Abbasi A R, Rezvani Z and Nejati K 2006 Dyes Pigm. 70 71-75
[14] Jeong M J, Park J H, Lee C and Chang J Y 2006 Org. Lett. 8 2221- 2224
[15] Jamain Z, Khairuddean M and Sa’aid S A 2019 J. Mol. Struct. 1186 293–302
[16] Irina C, Ana M S, Daniela A, Valentina A and Dan S 2007 Liq. Cryst. 34 775-785
[17] Sakagami S and Nakamizo M 1980 Bull. Chem. Soc. Jpn. 53 265–266
[18] Jamain Z, Khairuddean M and Tay G S 2020 RSC Adv. 10 28918–28934
[19] Jamain Z, Khairuddean M and Tay G S 2020 Int. J. Mol. Sci. 21 4267
[20] Galewski Z and Coles H J 1999 J. Mol. Liq. 79 77–87
[21] Jamain Z, Khairuddean M and Tay G S 2020 Molecules 25 2122
[22] Nagaveni N G, Roy A and Prasad V 2012 J. Mater. Chem. 18 8948–8959