

PREPARATION OF LIQUID CRYSTALS USING VARIOUS ALKYL CHAINS  
WITH NITRO GROUP AS TERMINAL

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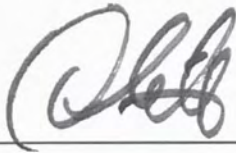
*For Tan,  
generous loaner, getaway driver and foulweather friend.*



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## DECLARATION

I hereby declare that his dissertation is based on my original work, except for quotations and summaries each of which have been fully acknowledged.



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**VERIFICATION**

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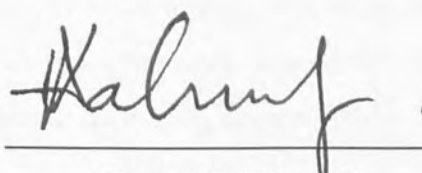
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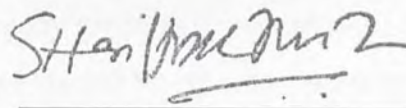
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## ABSTRACT

The objective is to synthesize and prepare three Liquid Crystal (LC) compounds with nitro group as terminal of differs only by their length of alkyl chains. The preparation started with synthesizing 4-(4-nitrophenylazo)phenol. Initially, it starts with the diazotization of *p*-nitroaniline to prepare the diazonium salt. The diazonium salt obtained then undergoes a coupling reaction with phenol, which produces 4-(4-nitrophenylazo)phenol in an ice bath to keep the whole reaction under 5 °C. The compound is then left crystallized. Later, three final products were obtained via Williamson Synthesis by reacting the 4-(4-nitrophenylazo)phenol with 1-bromohexane, 1-bromodecane, and 1-bromohexadecane – producing the three 4-(4-nitrophenylazophenoxy)hexane, 4-(4-nitrophenylazophenoxy)decane, and 4-(4-nitrophenylazophenoxy)hexadecane respectfully. They are then purified and recrystallized. A structure molecule and phase analysis are done via FTIR, <sup>1</sup>H-NMR spectroscopy and DSC. The functional groups found are identical with the correspond compounds, and so does it's molecular structure. Enthalpies were also obtained but not the mesophase for all LCs.

**PENYEDIAAN HABLUR CECAIR MENGGUNAKAN PELBAGAI RANTAI  
ALKIL DENGAN KUMPULAN NITRO SEBAGAI TERMINAL.**

**ABSTRAK**

*Objektif disertasi ini adalah untuk mensintesis dan menyediakan tiga bahan hablur cecair dengan kumpulan nitro sebagai terminal dan hanya berbeza pada panjang rantai alkil. Penyediaan bermula dengan mensintesis 4-(4-nitrofenilazo)fenol. Ia dimulakan dengan proses diazotization p-nitroaniline untuk menyediakan garam diazonium. Garam diazonium yang diperolehi kemudiannya ditindakbalas coupling dengan fenol, yang menghasilkan 4-(4-nitrofenilazo)fenol dalam mandian ais untuk mengekalkan tindakbalas dibawah suhu 5 °C. Bahan terhasil kemudiannya dibiarkan menghablur. Kemudian, tiga produk akhir diperolehi melalui sintesis Williamson dengan mengtindakbalaskan 4-(4-nitrofenilazo)fenol dengan 1-bromoheksana, 1-bromodekana, dan 1-bromoheksadekana – menghasilkan ketiga-tiga 4-(4-nitrofenilazofenoksi)heksana, 4-(4-nitrofenilazofenoksi)dekana, 4-(4-nitrofenilazofenoksi)heksadekana. Mereka kemudiannya ditulenkan dan dihablurkan sekali lagi. Struktur molekul dan fasa dianalisis menggunakan spektroskopi FTIR, <sup>1</sup>H-NMR dan DSC. Kumpulan berfungsi yang ditemui adalah berpadanan dengan bahan-bahan tersebut, begitu juga struktur molekul mereka. Entalpi-entalpi juga diperolehi tetapi tiada fasameso bagi kesemua hablur cecair.*



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## LIST OF SYMBOLS & ABBREVIATION

$\beta$	angle between molecular symmetry axis and director
$\langle P_2 \rangle$	long-range molecular order
$l\alpha$	direction cosines between director and molecular axes
$l\beta$	direction cosines between director and molecular axes
$\delta\alpha\beta$	Kronecker delta
$L$	even integer
$\langle P_L \rangle$	order parameters
$n$	director orientation
$i$	axis of liquid crystal molecules
$j$	axis of liquid crystal molecules
$n_i$	$i^{\text{th}}$ director component
$x_j$	coordinate on axis
$D_{\sigma h}$	nematic structure in Schoenflies notation
$N_u$	uniaxial phase
SmA	smectic A mesophase
SmB	smectic B mesophase
SmC	smectic C mesophase
SmF	smectic F mesophase
SmI	smectic I mesophase



$Z$	optic axis
$SmA^*$	chiral smectic A mesophase
$SmB^*$	chiral smectic B mesophase
$SmC^*$	chiral smectic C mesophase
$SmF^*$	chiral smectic F mesophase
$SmI^*$	chiral smectic I mesophase
$D_{6h}$	point group symmetry
$SmB_{hex}$	hexagonal smectic B mesophase
$C_{2h}(2/m)$	point-group symmetry
$I(2/m)$	space group



## CHAPTER 1

### INTRODUCTION

#### 1.1 Liquid Crystal

According to Daintith (2004), liquid crystal (LC) is a state of matter which is more ordered, meaning to say that it is arranged or organized, than a liquid but less ordered than a solid. Its state was first discovered in 1888, and since the early 19<sup>th</sup> century that such crystals have been developed for use in our everyday appliances such as digital watches, calculators and portable computer screens. Liquid crystal materials are unique in their characteristics, properties and uses. Every now and then, new applications are developed thus, LC play an important role in the modern technology. Generally, LC materials have several common characteristics. Among these are rod-like molecular structures, rigidity (stiff and difficult to move or bend) of the long axis, and strong dipoles and easily polarisable substituents.

Nematic crystals, for example, have long molecules all aligned in the same direction, but otherwise randomly arranged. Cholesteric and smectic liquid crystals, however, also have aligned molecules that are arranged in clearly different layers. In

cholesteric crystals, the axes of the molecules are parallel to the plane of the layers (Daintith, 2004).

According to Collyer (1992), there are few types of classification of liquid crystals. The distinguishing characteristic of the liquid crystalline state is the tendency of the molecules (mesogens) to point along a common axis, called the director. This is in vice versa to molecules in the liquid phase, which have no intrinsic order. In the solid state, molecules are highly ordered and have little translational (to move from one place to another) freedom. The characteristic orientational order of the LC state is between the traditional solid and liquid phases and this is the origin of the term mesogenic state, and it is used synonymously with LC state. Liquid crystal technology has had a major effect in many areas of science and engineering, as well as device technology. Applications for this material are still being discovered and continue to provide effective solutions to many different problems from out typical everyday needs to our latest laptop CrystalBrite<sup>®</sup> LCDs. Liquid crystal displays are the most common application of LC technology these days. An LCD consists of an array of tiny segments (pixels) that can be manipulated to present information. This basic idea is common to all displays, ranging from simple calculators to full interactive plasma screen televisions.

Chiral nematic (cholesteric) liquid crystals reflect light with a wavelength equal to the pitch. Because the pitch is dependent upon temperature, the colour reflected also is dependent upon temperature. LC makes it possible to accurately gauge temperature just by looking at the colour of the thermometer. By mixing different compounds, a device for practically any temperature range can be built. More



important and practical applications have been developed in such diverse areas as medicine and electronics. Special LC devices can be attached to the skin to show a "map" of temperatures. LC temperature sensors can also be used to find bad connections on a circuit board by detecting the characteristic higher temperature (<http://www.sharp.com>).

An application of liquid crystals that is only now being explored is optical imaging and recording. In this technology, an LC cell is placed between two layers of photoconductor. Light is applied to the photoconductor, which increases the material's conductivity. This causes an electric field to develop in the liquid crystal corresponding to the intensity of the light. The electric pattern can be transmitted by an electrode, which enables the image to be recorded. This technology is still being developed and is one of the most promising areas of LC research. LCs have a multitude of other uses. They are used for non-destructive mechanical testing of materials under stress. This technique is also used for the visualization of radio frequency waves in waveguides. They are used in medical applications where, for example, transient pressure transmitted by a walking foot on the ground is measured. Low molar mass LCs have applications including erasable optical disks, full colour "electronic slides" for computer-aided drawing, and light modulators for colour electronic imaging (<http://en.wikipedia.org>).

## 1.2 Objectives

- i. To prepare liquid crystals using various alkyl chains with nitro group as terminal.

- ii. To determine the structure of liquid crystal using Fourier Transform Infra Red Spectroscopy (FTIR) and Nuclear Magnetic Resonance Spectroscopy (NMR).
- iii. To determine the phase condition by Differential Scanning Calorimeter (DSC).

### 1.3 Scope

This project focused on some of the various ways of preparing liquid crystals, depending on the end product wanted. Organic syntheses are the main steps in achieving the types of liquid crystal wanted. There are three types of liquid crystals wanted, differ in length of the alkyl groups:

- a. 4-(4-Nitrophenylazophenoxy)hexane
- b. 4-(4-Nitrophenylazophenoxy)decane
- c. 4-(4-Nitrophenylazophenoxy)hexadecane

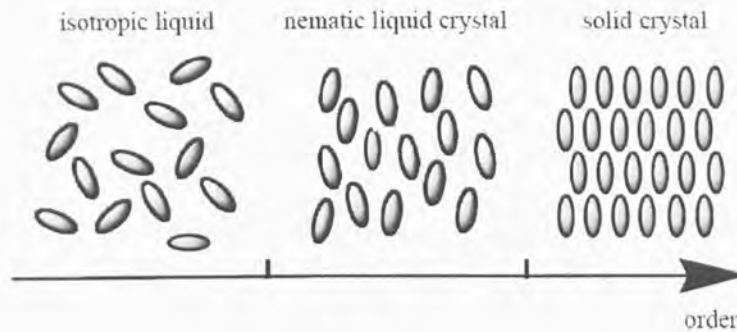
The procedures involved are such as refluxes, crystallization and etherification using ordered chemicals from manufactures selected and basic chemicals available from the laboratory like acetone, dichloromethane, methanol and chloroform. Instrument used are that of available in the laboratory and for molecular determination, a permeation to used the FTIR and NMR available at Institute of Tropical Borneo Research, and phase transition using the available DSC at the Industrial Chemistry laboratory.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Liquid Crystal

Liquid crystal is a state of matter which is more ordered than a liquid but less ordered than a solid. Although the liquid crystal state was first noticed as long ago in 1888, it is only since the early 1970s that such crystals have been developed for use in digital, calculators, computer screens, and cell-phones. A mesomorphic state having long-range orientational order and either partial positional order or complete positional disorder. In the LC state, a substance combines the properties of a liquid and a crystalline solid. The LC state occurs between the crystalline solid and the isotropic liquid states on varying, for example, the temperature (Hunt, 2003).



**Figure 2.1** The isotropic liquid, the nematic liquid crystal, and the solid crystal phase with director of the liquid crystal, indicating the average direction of the particles, are vertical (Source: Barón & Stepto, 2002).

A liquid crystal is a phase (Figure 2.1) occurring over a definite temperature range within the LC state, a substance in the LC state, and a pronounced anisotropy in the shapes and interactions of molecules, molecular moieties, or molecular aggregates are necessary for the formation of liquid crystals (Barón & Stepto, 2002).

### 2.1.1 Thermotropic Liquid Crystal

A liquid crystal (LC) is thermotropic if the order of its components is determined or changed by temperature. If temperature is too high, the rise in energy and therefore in motion of the components will induce a phase change: the LC will become an isotropic liquid. If, the temperature is too low to support a thermotropic phase, the LC will become a crystal. Therefore, a range of temperatures at which we observe thermotropic LCs; and most of these have several "subphases" (nematic & smectic), which we may observe by modifying the temperature (<http://en.wikipedia.org>).



## REFERENCE

- Abdalla M. Khedr and Mohamed Gaber, 2005. Spectrophotometric Studies of the Reaction of Zinc(II) with Some Azo-Triazol Compounds and Its Application to the Spectrophotometric Determination of Microamounts of Zinc(II). *Spectroscopy Letters*. **38**, 431-445.
- Abdullah M. A., Abood A. B., Iqbal M. I. I., and Fatani, N. A., 2006. Novel Dyes Derived from Hydrazones: Part 3. Synthesis and Characterizations of 2-[4-(1phenylethylidene)hydrazine]phenylethylene-1, 1,2-tricarbonitrile. *Dyes and Pigments*. **71**, 103-108.
- Amir R. A., Zolfaghar, R., and Kamellia, N., 2006. Synthesis and Properties of New Liquid Crystalline Compounds Containing an Alkoxyphenylazo Group. *Dyes and Pigments*. **70**, 71-75.
- Barón, M., 2001. Definitions for Basic Terms Relating to Low-Molar-Mass and Polymer Liquid Crystals. *Pure Appl. Chem.* **73** (5), 845–895.
- Barón, M. and Stepto, R. F. T., 2002. Definitions of Basic Terms Relating to Polymer Liquid Crystals. *Pure Appl. Chem.* **74**, 493–509.
- Brostow, W. (eds.), 1996. *Polymer Liquid Crystals Mechanical and Thermophysical Properties*. Chapman & Hall, London.

- Bruice, P. Y., 2004. *Organic Chemistry*. 4<sup>th</sup> ed. Pearson Education, Inc., New York.
- Buffeteau, T., Natansohn, A., Rochan, P., and Pezolet, M., 1996. *Macromolecules*. **29**, 8783.
- Chen, Y., Harrison, W. T. A., Imrie, C. T., and Ryder, K. S., 2002. Pyrrole and Polypyrrole-based Liquid Crystals Containing Azobenzene Mesogenic Groups. *J. Mater. Chem.* **12**, 579-585.
- Canessa, G., Aguilera, C., Serrano, J., and Oriol, L., 1996. *Polymer Chemistry. Polymer Science*. **34**, 1465.
- Collings, P. J., and Hird, M., 1997. *Introduction to Liquid Crystals: Chemistry and Physics*. Taylor & Francis, Bristol, PA.
- Collyer, A. A. (eds.), 1992. *Liquid Crystal Polymers: From Structure to Applications*. Elsevier Science Publishers Ltd. London.
- Crews, P., Rodriguez, J., and Jaspars, M., 1998. *Organic Structure Analysis*. Oxford University Press, New York.
- Daintith, J. (eds.), 2004. *Oxford Dictionary of Chemistry*. 5<sup>th</sup> ed. Oxford University Press, New York.



Demus, D., Gray, G. W., Spiess, H. W., and Vill, V. (eds.), 1998. *Handbook of Liquid Crystals*. Wiley-VCH, Weinheim.

Donald, A. M. and Windle, A. H., 1992. *Liquid Crystalline Polymers*. Cambridge University Press, Cambridge.

*Excalibur Spectrometer Manual: FTS 3000 & FTS 4000 Series*, 2000. Bio-Rad Laboratories, Inc., Cambridge.

Fuhrhop, J.-H. and Li, G., 2003. *Organic Synthesis: Concepts and Methods*. WILEY-VCH Verlag GmbH & Co., Weinheim.

Freilberg, S. M., 1998. *Synthesis & Characterization of Two Azo-containing Side Chain Liquid Crystal Polymers*. Queen's University, Canada.

Hyde, S. T., 2001. *Handbook of Applied Surface and Colloid Chemistry: Identification of Lyotropic Liquid Crystalline Mesophases*. John Wiley & Sons, Ltd., New York.

[http://en.wikipedia.org/wiki/Liquid\\_crystals.html](http://en.wikipedia.org/wiki/Liquid_crystals.html)

<http://holmes.canres.nottingham.ac.uk/mrg/ianw/thesis/node6.html>

<http://www.organic-chemistry.org/frames.html>



<http://www.organic-chemistry.org/namedreactions/williamson-synthesis.html>

<http://www.sharp.org/lcddisplays.html>

Hunt, A. (eds.), 2003. *Schaum's A-Z Chemistry*. McGraw-Hill, London.

Kulkarni, M., Kothawade, S., Arabale, G., Wagh, D., Vijayamohanan, K., Kulkarni, R. A., and Vernekar, S. P., 2005. Synthesis and Characterization of Polyimides and Co-polyimides Having Pendant Benzoic Acid Moiety. *Polymer*. **46**, 3669-3676.

Oxtoby, D. W., Gillis, H. P., and Nachtrieb, N. H., 2002. *Principles of Modern Chemistry*. 5<sup>th</sup> ed. Thomson Learning Inc., USA.

Laue, T. and Plagens, A., 1998. *Named Organic Reactions*. John Wiley & Sons Ltd., West Sussex.

Lehman, J. W., 2004. *Microscale Operational Organic Chemistry: A Problem-Solving Approach to the Laboratory Course*. Pearson Education Inc., New Jersey.

Lewis, E. S., and Hanson, M., P., 1967. *Journals of American Chemistry Society*. **89**, 6268.

Lewis, Sr. R. J., 1993. *Hawley's Condensed Chemical Dictionary*. Van Nostrand Reinhold Company, New York.





- Liquid Crystals*, 1994. Volume 3: Topics in Physical Chemistry. Stegmeyer, H. (eds.), Springer-Verlag, New York.
- Loudon, G. M., 1995. *Organic Chemistry*. 3<sup>rd</sup> ed. Benjamin/Cummings Publishing Company, Inc., Canada.
- Luckhurst, G. R. and Veracini, C. A. (eds.), 1994. *The Molecular Dynamics of Liquid Crystals*. Kluwer, Dordrecht.
- Lutfor, M. R., Igbal, M. H., Silong, S., Rahman, M. Z. A., and Wan Yunus, W. M. Z., 2005. Synthesis and Characterization of Triphenylene-Based Discotic Liquid Crystalline Monomers Containing Azobenzene Moieties. *Borneo Science* **17**, 1-9.
- Lutfor, M. R., Tschierske, C., Yusoff, M., and Silong, S., 2005. Synthesis and Liquid Crystalline Properties of a Disc-shaped Molecule with Azobenzene at the Periphery. *Tetrahedron Letters* **46**, 2303-2305.
- Lydon, J. E., 1998. Chromonic Liquid Crystal Phases. *Current Opinion in Colloid & Interface Science* **3**, 458-466.
- McMurry, J., 1996. *Organic Chemistry*. 4<sup>th</sup> ed. Brooks/Cole Publishing Company, USA.



- Pillai, C. K. S., Ysandaya, K., Sudha J. D., and Saminathan, M., 2003. Influence of Hydrogen Bonding on the Generation & Stabilization of Liquid Crystalline Polyesters, Poly(esteramide)s, & Polyacrylates. *Pramana – Journal of Physics* **61**, 417-423.
- Saunders, H. and Allen, R. L. M., 1985. *Aromatic Diazo Compounds*. 3<sup>rd</sup> ed. Edward Arnold, London.
- Schmid, G. H., 1996. *Organic Chemistry*. Mosby-Year Book, Inc., Missouri.
- Shibaev, V. P. and Lam, L. (eds.), 1994. *Liquid Crystalline and Mesomorphic Polymers*. Springer-Verlag, New York.
- Silberberg, M. S., 2003. *Chemistry: The Molecular Nature of Matter and Change*. 3<sup>rd</sup> ed. McGraw-Hill Companies, Inc., New York.
- So, B-K., Jang, M-C., Park, J-H., Lee, K-S., Song, H. H., and Lee, S-M., 2002. *Opt. Mater.* **21**, 685.
- So, B-K., Kim, H-J., Lee, S-M., Song, H. H., and Park, J-H., 2006. Novel Bent-shaped Liquid Crystal Compounds: IV. Dimesogenic Compounds Containing 2-hydroxy-1,3-dioxypyrene and Azobenzene Mesogens. *Dye and Pigments*. **70**, 38-42.



- Solomons, T. W. G. and Fryhle, C. B., 2004. *Organic Chemistry*. 8<sup>th</sup> ed. John Wiley & Sons, Inc., USA.
- Swain, C. G., Sheats, J. E., and Harbison, K. G., 1975. *Journals of American Chemistry Society*. **97**, 783.
- Sybil, P. (eds.), 1993. *McGraw-Hill Encyclopaedia of Chemistry*. 2<sup>nd</sup> ed. McGraw-Hill Inc., New York.
- Wade, L. G. Jr., 1995. *Organic Chemistry*. 3<sup>rd</sup> ed. Prentice Hall, New Jersey.
- Wolff, D., Ruhmary, R., Theiles, T., Prescher, D., and Springer, J., 1996. *Liquid Crystal*. **20**, 553.
- Yagci, Y., Sehatli, I. E., Kubisa, D., and Biedron, T., 1993. Synthesis of Block Copolymers by Combination of an Activated Monomer & Free Radical Polymerization Mechanism. *Macromolecules* **23**, 2397-2399.
- Yang, W., You, X-L., Zhang, Y., and Zhang, D-C., 2006. The Crystal Structure of 2',6'-dichloro-4-dimethylaminoazobenzene. *Dyes and Pigments*. **68**, 27-31.
- Zollinger, H., 1961. *Azo and Diazo Chemistry*. Interscience, New York.

