

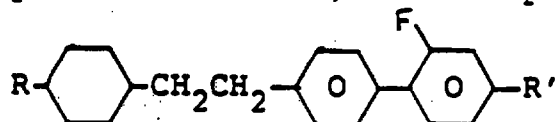
LIQUID CRYSTAL CYANOALKANES AND CYANOALKENES

This invention relates to cyanoalkanes and cyanoalkenes which show liquid crystalline properties, and to liquid crystal materials and devices which incorporate them.

Liquid crystal materials and devices are well known, and generally exploit the useful nematic (N) and smectic (S), especially smectic C and I (S_C , S_I) liquid crystal phases, which show electro-optical characteristics. The S_C phase shows its most useful characteristics when an optically active compound is present in the material, forming a ferroelectric chiral smectic C (Sc^*) phase.

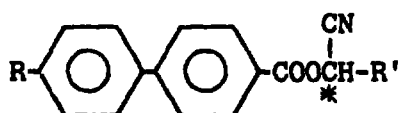
Liquid crystal materials are generally mixtures of compounds, and desirable requirements for such a mixture and/or its constituent compounds include ease of preparation and liquid crystal phases of a useful type which persist over a broad temperature range preferably including room temperature. Other desirable requirements may be sought for particular applications, for example a useful birefringence, dielectric anisotropy, a useful phase transition sequence such as Sc - SA with increasing temperature, and in the case of Sc materials, the ability to form a mixture with a high spontaneous polarisation (P_s).

A wide variety of compounds which show liquid crystal phases are known, for example:



-2-

compounds where R and R' are alkyl, disclosed in EP-A-0,117,631. Another useful structural type for example is:

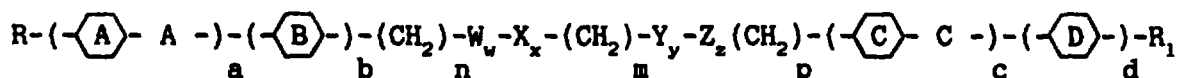


where R and R' are alkyl, disclosed in PCT/GB87/00441.

It is widely acknowledged that minor structural variations in liquid crystal compounds can have a drastic and unexpected effect on their liquid crystalline properties. It is therefore an object of this invention to explore novel structural types and identify those which show liquid crystal phases, especially of a useful type.

According to this invention a ferroelectric liquid crystal mixture including at least one compound of general formula I is provided:

Formula I



wherein R and R₁ are independently C₁-C₁₂ alkyl, alkoxy, perfluoroalkyl or perfluoroalkoxy;

rings A, B, C and D are independently phenyl, which may carry one or two halogen substituents, trans-cyclohexyl, or (2,2,2) bicyclooctyl, each of a, b, c or d being independently 0 or 1 provided (a+b+c+d) is 2 or 3 and further that c+d = 0 only when A and B are both cyclohexyl;

links A and C are independently a single bond, CH₂CH₂, COO, OOC, CH₂O or OCH₂;

-3-

n, m and p are independently 0 or an integer 1 to 4 provided (n+m+p) is not 0 except when the linking group between B and C is $\text{HC}=\text{C}(\text{CN})-$;

W and Z are independently selected from $-\text{CH}=\text{C}(\text{CN})-$ and $-\text{C}(\text{CN})=\text{CH}-$;

X and Y are independently selected from $-\text{CHCN}-$ and $-\text{C}(\text{CN})_2-$;

w, x, y and z are 0 or 1, provided that w and z are 0 if x and/or y are 1, and further provided that at least one of w, x, y and z is 1.

R and R_1 may be straight chain or branched chain, including asymmetrically substituted chains. When rings A, B, C or D carry substituents these may be in any of the available substitution positions. When a unit $-\text{CHCN}-$ is present it may be asymmetrically substituted or a racemate.

The structural preferences discussed below are inter-alia on the basis of ease of preparation and/or usefulness in liquid crystal materials.

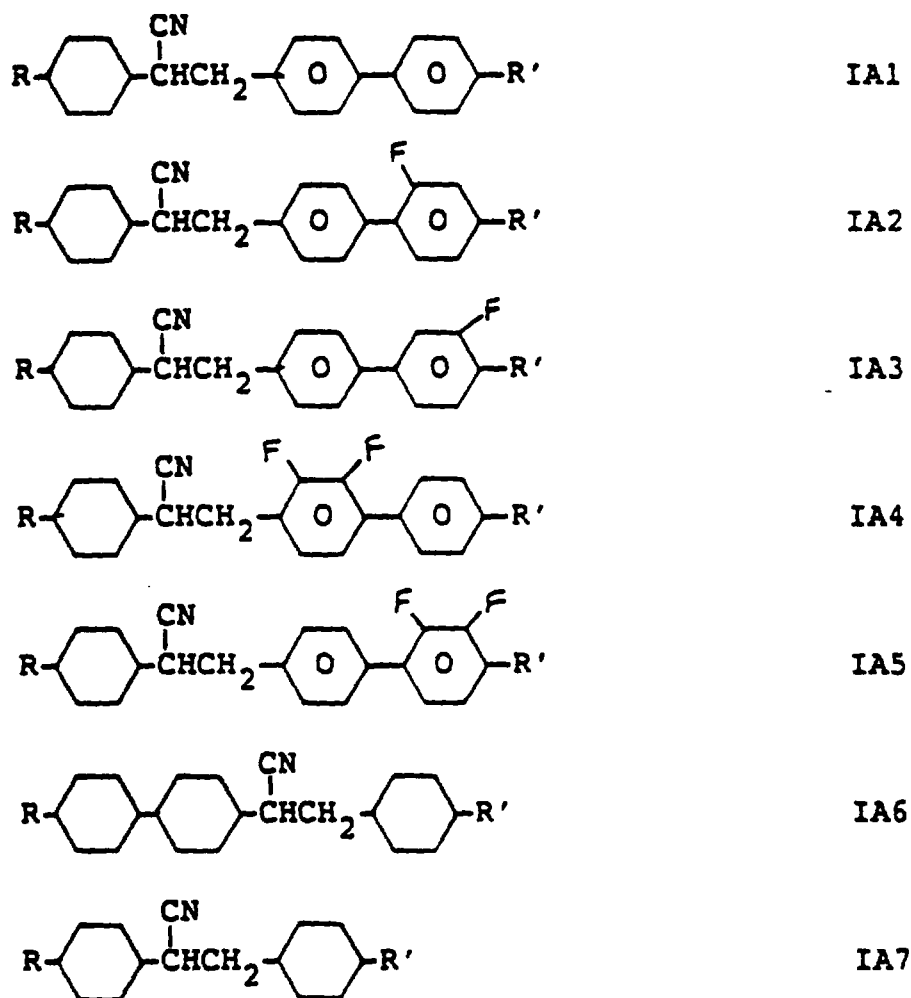
Preferably R and R_1 are independently n-alkyl or n-alkoxy, or asymmetrically substituted alkyl or alkoxy. Preferably rings A and B are cyclohexyl. Preferably if rings C and D are halogen substituted phenyl the halogen is fluorine. Preferably the links A and C are single bonds. Preferably if c and d are 0, R_1 is alkyl. Preferably only ring A is (2,2,2) bicyclooctyl.

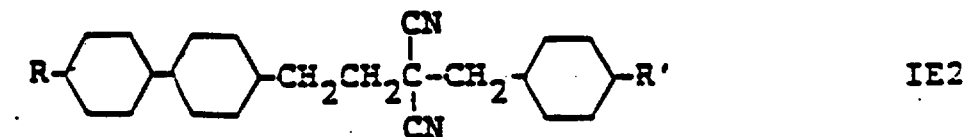
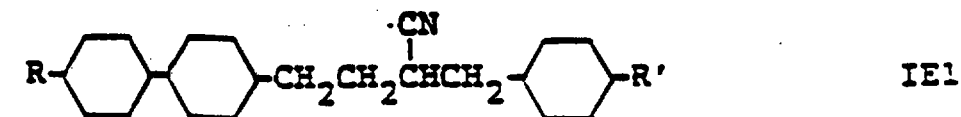
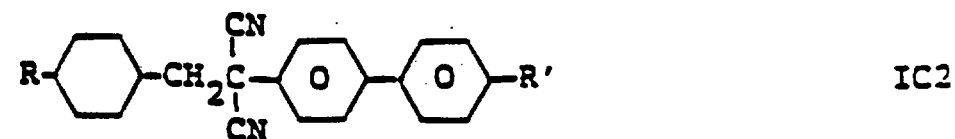
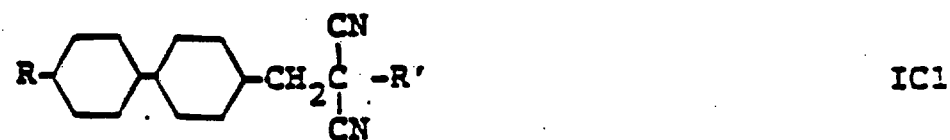
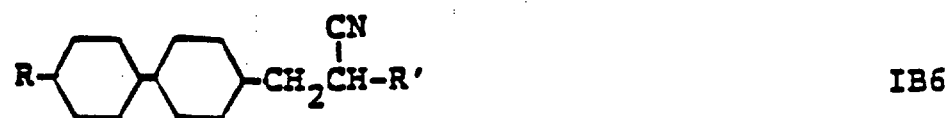
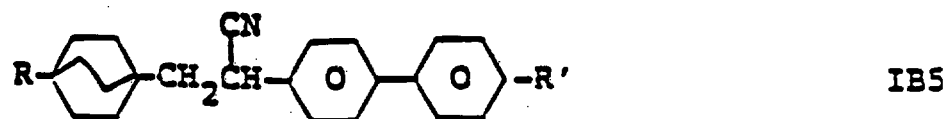
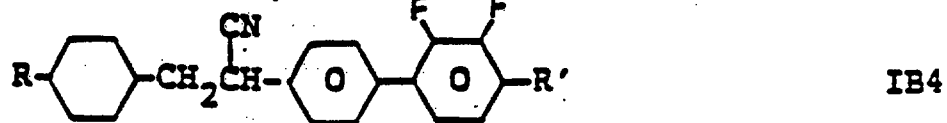
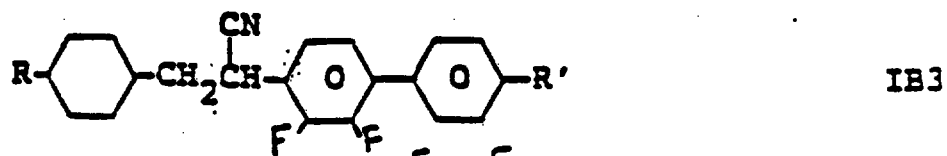
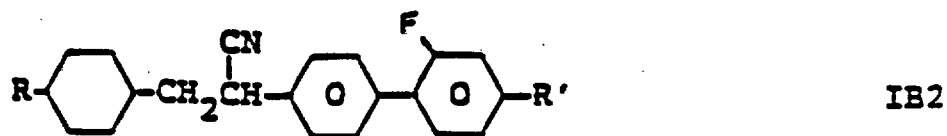
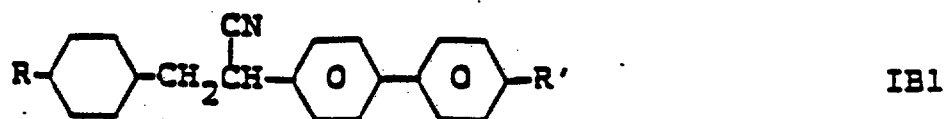
Some preferred combinations of the variables relating to the cyanoalkane or cyanoalkene bridge between rings B and C shown in formula I are :

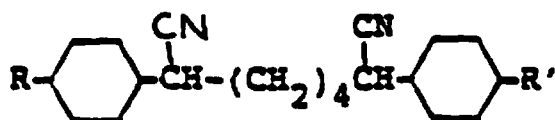
- (A) $n, w, y, z, p = 0; x, m = 1; X = \text{CHCN}$
 (B) $w, m, y, z, p = 0; n, x = 1; X = \text{CHCN}$
 (C) $w, m, y, z, p = 0; n, x = 1, X = \text{C}(\text{CN})_2$
 (D) $n, x, m, y, z, p = 0; w = 1; W = -\text{CH}=\text{C}(\text{CN})-$
 (E) $w, y, z, p = 0; x, m = 1; n = 2; X = \text{CHCN}$ or $\text{C}(\text{CN})_2$
 (F) $n, w, z, p = 0; x, y = 1; m = 4; X, Y = \text{CHCN}$

Specific examples of structures embodying these combinations are listed below in table 1 wherein the capital letter indicates the combination represented.

Table 1







IF1

Of these formulae, IA1, IA4, IA5, IB2, IB3 and IB4 are particularly preferred.

Compounds of formula I, for example those listed in Table 1, may be prepared by a number of preparative routes starting from known compounds, or by variants of these which will be apparent to a skilled chemist. General routes A and B to compounds IA and IB are shown schematically in the accompanying figures.

Steps A1 and B1 use lithiumdiisopropylamide (LDA) as a coupling reagent, and steps A2 and B2 involve coupling of the brominated product with a phenyl boronic acid. Methods for preparation of phenylboronic acids are well known, for example, reaction of a starting phenyl with tri-isopropylborate. By using an appropriately substituted starting phenyl, e.g. a 2- or 3-fluoro, or 2, 3-difluoro alkyl or alkoxy phenyl, the corresponding 4-phenyl boronic acid may be prepared.

Methods for preparation of such phenylboronic acids are shown in route G.

In route G the steps are as follows :

- G1: 1-bromoalkane, K_2CO_3 , acetone, reflux
- G2: react with n-butyllithium, then tri-isopropylborate at -78°C
- G3: Friedel Crafts addition
- G4: Reduction, e.g. using hydrazine hydrate
- G5: See M. F. Hawthorne, J. Org. Chem. (1957), 22, 1001
- G6: n-butyllithium
- G7: R-CHO
- G8: (i) P_2O_5 , (ii) Pd/C, H_2

Examples of the use of route G to prepare phenyl boronic acids are described in GB-A-8806220 and PCT/EP88/00724, the contents of which are included by reference.

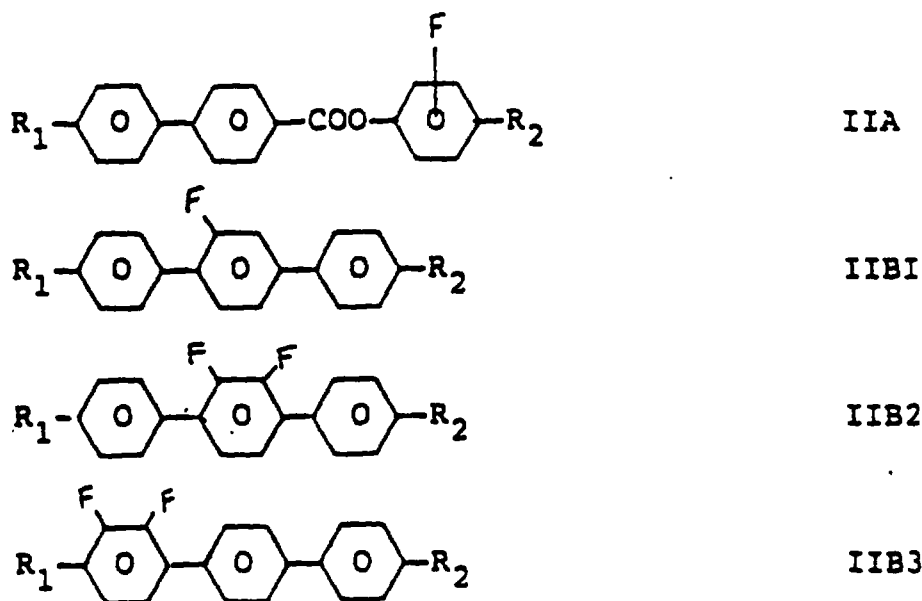
Hence routes A and B are of general applicability and although illustrated for specific structures it will be apparent to those skilled in the art how they can be adapted to produce other structural types.

Compounds of structural types C, D and E, e.g. IC, ID and IF may be prepared by reaction of the corresponding Ketone with trimethylsilylcyanide (TMS-CN) after reaction of the Ketone with titanium tetrachloride. Many suitable Ketones are known, but synthetic routes to Ketones are so well known, e.g. Friedel Crafts type additions using acyl chlorides or reaction of nitriles with Grignard reagents that if commercially unavailable they may be synthesised.

Compounds of formula I may be mixed with known liquid crystalline compounds to form useful liquid crystal materials. This invention therefore also provides a liquid crystal material, being a mixture of compounds at least one of which is a compound of formula I. In this aspect of the invention, compounds of structural types A and B e.g. IA and IB are preferred as constituents of smectic C liquid crystal materials, in view of the fact that they show Sc phases, have a negative dielectric anisotropy ($\Delta\epsilon$) and a low birefringence (Δn).

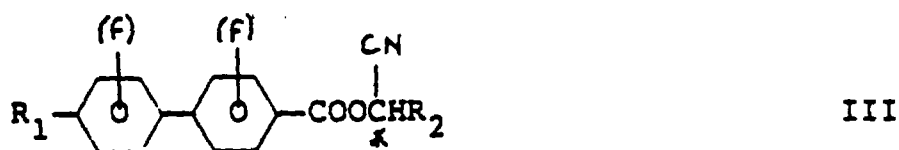
Compounds of formula I, e.g. of structural types A and B, especially IA and IB may be used in Sc mixtures together with known compounds with either together or separately form an Sc phase, particularly preferred

compounds of this type being those of formulae IIA and IIB below:



wherein R_1 and R_2 are independently C_2-C_{12} alkyl or alkoxy.

If the compound(s) of formula I present in the Sc mixture contains an asymmetrically substituted group, for example if R, R' or -CH (CN)- is asymmetrically substituted, then the Sc phase may be a ferroelectric Sc^{*} phase. Alternately or additionally the mixture may contain known asymmetrically substituted compounds which are capable of inducing Sc phases to be Sc^{*} phases. Many such compounds are known, but preferred compounds are those described in PCT/GB87/00441, especially those of formula III



where (F) indicates that the ring indicated may carry a lateral fluorine substituent and R_1 may be C_{1-12} n-alkyl or n-alkoxy and R_2 may be C_{1-15} alkyl, or n-alkyl or a branched chain or optically active alkyl.

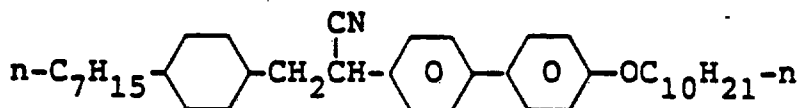
Typically but not exclusively and SC^* mixture of this aspect of the invention contains up to 95 wt % of compounds of formula IIA or IIB, up to 15 wt % of a compound formula III, and up to 25 wt % of a compound of formula I, the total being 100 wt %.

Liquid crystal materials of this aspect of the invention may be used in the known types of liquid crystal electro-optical display device.

Examples of the invention will now be described, referring to Figs 1, 2 and 3 which schematically show preparative routes to compounds of formula I. In each case the boronic acids were prepared using the methods described in the examples of PCT/EP88/00724. In each case all liquid crystal transition temperatures are in $^{\circ}C$, eg K70 SA means solid crystal to SA liquid crystal at $70^{\circ}C$.

Example 1 Route B

(1) Preparation of



B1 1-(4-Bromophenyl)-1-cyano-2-(trans-4-heptylcyclohexyl)ethane

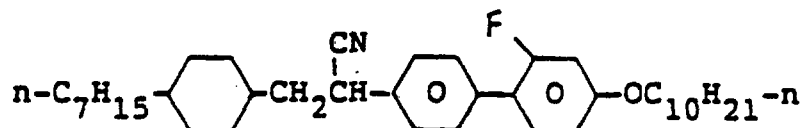
Lithiumdiisopropylamide (LDA) (1.5 in THF) (5.13 ml, 7.7 mmol) was added dropwise under dry nitrogen to a stirred and cooled (-70°C) mixture of trans-4-heptylcyclohexylmethyl-toluene-4-sulphonate (2.8g, 7.7 mmol) and 4-bromophenylacetonitrile (1.37g, 7.0 mmol) in sodium-dried tetrahydrofuran (10 ml) and molecular sieve-dried hexamethylphosphoramide (HMPA) (5 ml). The reaction mixture was stirred for 1 h at -70°C and then allowed to warm to room temperature overnight and monitored by GC. The reaction mixture was poured onto water (50 ml) and the product was extracted into ether (2 x 20 ml). The combined extracts were washed with water and dried (MgSO₄). The solvent was removed under reduced pressure and the crude product was purified by column chromatography [silica gel; eluting with chloroform-light petroleum(bp 40-60°C)(1:2)]; yield 1.43g, 52% mp 56-57°C.

B2 1-Cyano-2-(4'-decyloxybiphenyl-4-yl)-1-(trans-4-heptylcyclohexyl)ethane

A stirred mixture of the product of step A1 (2.64 mmol), 4-decyloxyphenylboronic acid (0.99g, 3.43 mmol), tetrakis(triphenylphosphine)palladium(0) (0.4g, 0.34 mmol), 2M sodium carbonate solution (3 ml), benzene (10 ml) and methanol (1 ml) was heated under reflux under dry nitrogen for 4 h and the reaction was monitored by GC. The reaction mixture was cooled and 2M sodium carbonate solution (100 ml) was added followed by aqueous ammonia (2 ml) and ether (100 ml). The organic layer was separated and the aqueous layer was washed with ether (50 ml). The combined ether extracts were washed with water and dried (MgSO₄). The solvent was removed under reduced pressure and the crude product was

purified by column chromatography [silica gel; eluting with dichloromethane: light petroleum (bp 60-80°C)(3.1)]. Yield 62%, recrystallised from ethanol.

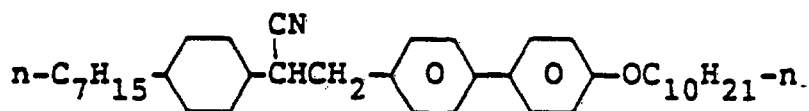
(2) Preparation of



This was prepared by an analogous method to that of (1) above using the product of Step B1 and 4-decyloxy-2-fluorophenylboronic acid. Election was on silica gel using dichloromethane: light petroleum (bp 40-60°C)(1:5). Yield 64% recrystallised from ethanol.

Example 2 Route A

(1) Preparation of



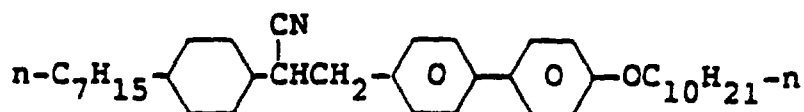
A1 1-(4-Bromophenyl)-2-cyano-2-(trans-4-heptylcyclohexyl)ethane

Was prepared similarly as step B1 of example 1 above from trans-4-heptylcyclohexylacetonitrile and 4-bromobenzylbromide; yield 59%; mp 60-62°C.

A2 1-Cyano-2-(4'-decoxybiphenyl-4-yl)-2-(trans-4-heptylcyclohexyl)ethane

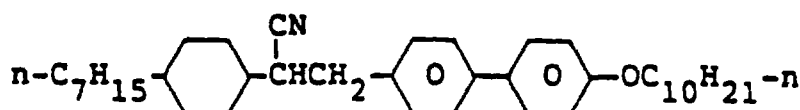
Was prepared similarly as for step B2 above using the product of step A1 and 4-decoxyphenylboronic acid. [silica gel; eluting with chloroform-light petroleum (bp 40-60°C)(1.5)]; yield 62% recrystallised from ethanol.

(2) Preparation of



Was prepared similarly as A1-A2 above using 1-(4-bromophenyl)-2-cyano-2-(trans-4-heptylcyclohexyl)-ethane and 4-decoxy-2-fluorophenylboronic acid. [Silica gel; eluting with dichloromethane-light petroleum (bp 40-60°C)(1:5)]; yield 36%; recrystallised from ethanol.

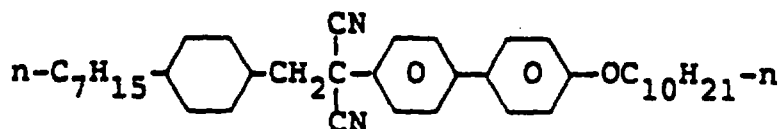
(3) Preparation of



Was prepared similarly as A1-A2 above using 1-(4-bromophenyl)-2-cyano-2-(trans-4-heptylcyclohexyl)-ethane and 4-decoxy-3-fluorophenylboronic acid. [Silica gel; eluting with dichloromethane-light petroleum (bp 40-60°C)(1:5)]; yield 27%; recrystallised from ethanol.

Example 3

Preparation of



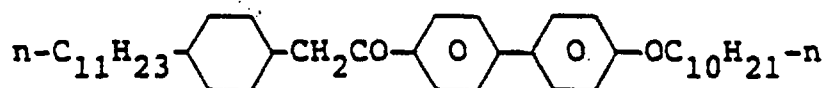
The Ketone 1-(4'-decyloxybiphenyl-4-yl)-2-(trans-4-heptylcyclohexyl) ethanone was prepared using a method analogous to that used for the corresponding octyloxy compound in Mol. Cryst. Liq. Cryst (1988). An alternate route was that of example 1 of EP-A-0117631. The yield was 18%.

Another route to this Ketone used the reaction between 1-(4-bromophenyl)-2-(trans-4-heptylcyclohexyl)-ethan-1-one (1.0 g, 2.64 mmol) and 4-decyloxyphenyl-boronic acid (0.99 g, 3.43 mmol) following a procedure analogous to that of B2 above. In the column chromatography stage silica gel was used and the eluent was dichloromethane: light petroleum (bp 40-60°C (1:1). Yield 0.85 g 61%, recrystallised from ethanol. The Ketone showed liquid crystal transitions K106 S_G 135 S_C 142 S_A 168 I.

To a solution of this Ketone (0.467 mmol) in molecular-sieve dried dichloromethane (5 ml) was added titanium tetrachloride (0.545 mmol, dropwise) at 0°C under dry nitrogen. After 30 minutes trimethylsilylcyanide (TMS-CN) (0.934 mmol) was added at 0°C and the mixture was stirred for 72 hours at room temperature.

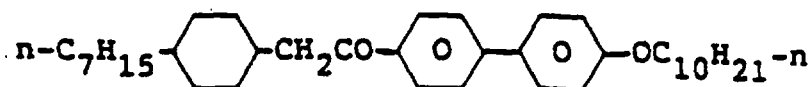
The reaction mixture was poured into water and the crude product was extracted into dichloromethane (2 x 25 ml). The combined extracts were washed with water and dried (MgSO₄). The solvent was removed under reduced pressure and the crude product was purified by column chromatography [(silica gel, eluting with dichloromethane: light petroleum (bp 40-60°C (1:5))]. The product was recrystallised from ethanol. Yield 50%.

Using analogous routes the following Ketones were prepared:

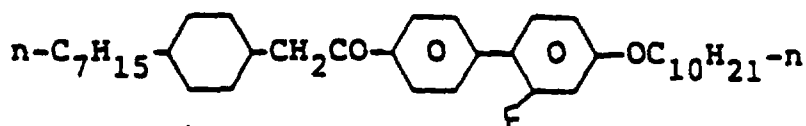


K 106 S_G 135 S_C 147 S_A 160 I

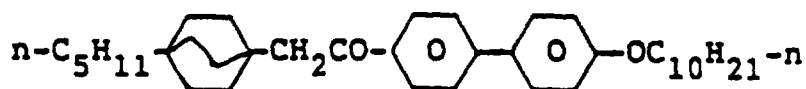
(eluent dichloromethane: light petroleum (40-60°C) 1:2, yield 26% recrystallised from ethanol).

K 117 S_G 132 S_C 141 S_A 163 I

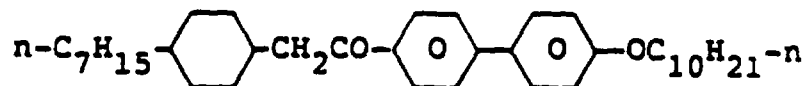
(eluent chloroform: light petroleum (40-60°C) 1:2,
yield 10% recrystallised from ethanol).

K (56 S_B) 58 S_A 128 I

(eluent dichloromethane: light petroleum (40-60°C) 4:1,
yield 93% recrystallised from light petroleum (40-60°C).

K 122 S_B 130 S_A 152 I

(prepared from 1-pentylbicyclo (2,2,2) octane 4-acetic
acid via the acyl chloride (via SOCl₂) and Mol. Cryst.
Liq. Cryst (1988) route. Eluent chloroform: light
petroleum (40-60°C) 1:2, yield 19%, recrystallised from
light petroleum (40-60°C).

K (56 S_B) 68 S_A 138 I

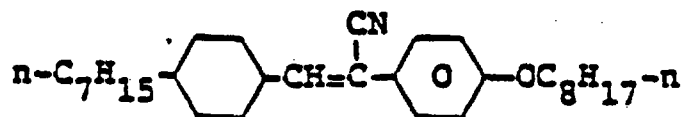
was prepared by another route as follows:

The Grignard reagent of 4-bromo-4'-decoxy-2-fluorobiphenyl (known) (6.1 g, 15 mmol), magnesium metal (0.4 g, 16.6 mg atom) in sodium-dried ether (25 ml) was prepared at 50°C under anhydrous conditions and the reaction was monitored by GC. A solution of trans-4-

heptylcyclohexyl-acetonitrile (1.1 g, 5 mmol) in sodium-dried ether (10 ml) was added and the reaction mixture was heated under reflux overnight. The reaction mixture was cooled and then poured onto ice (100 g) and 36% hydrochloric acid (10 ml). The organic layer was separated and the aqueous layer was washed with ether (25 ml). The combined ether extracts were washed with aqueous sodium carbonate (10%) (50 ml), water and then dried (MgSO_4). The solvent was removed under reduced pressure and the crude product was purified by column chromatography [silica gel; eluting with chloroform: light petroleum (bp 40-60°C) (1:2)]; yield 1.75 g, 64%; recrystallised from ethanol.

Example 4

Preparation of

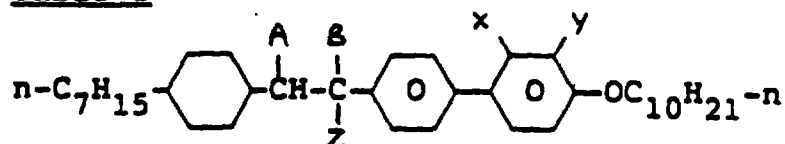


Titanium tetrachloride (55 μl , 0.545 mmol) was added dropwise to a solution of 2-(trans-4-heptylcyclohexyl)-1-(4-octoxyphenyl)ethanone (0.2 g, 0.467 mmol) in molecular sieve-dried dichloromethane (5 ml) at 0°C under dry nitrogen. After 30 min, TMS-CN (0.142 ml, 0.934 mmol) was added at 0°C and then the mixture was stirred for 72 h at room temperature. The reaction mixture was poured onto water and the crude product was extracted into dichloromethane (2 x 25 ml).

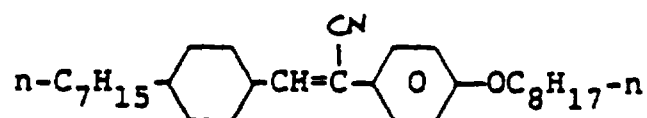
The combined extracts were washed with water and dried (MgSO_4). The solvent was removed under reduced pressure and the crude product was purified by column chromatography [silica gel; eluting with dichloromethane: light petroleum (bp 40-60°C) (1:2)]; yield 0.15 g, 68%; recrystallised from ethanol.

Liquid crystal transitions (in °C) of the cyano compounds prepared in the above examples and by related methods are listed below:

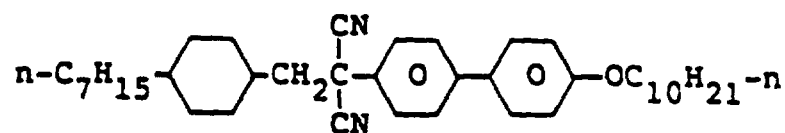
Table 2



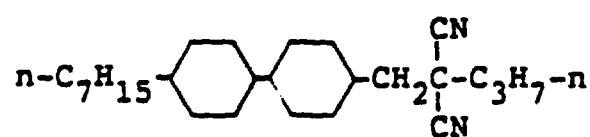
A	B	Z	X	Y	K	S _B	S _C	S _A	N	I
CN	H	H	H	H	86	→	(75)	→	124	
H	CN	H	F	H	70	→			(65)	
CN	H	H	F	H	52	→	(47)	→	(67)	→ 90
CN	H	H	H	F	89	→			126	
H	CN	H	H	H			72	→	99	



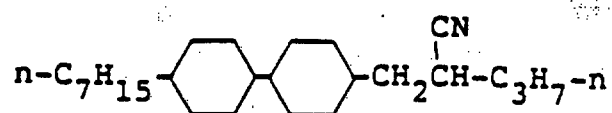
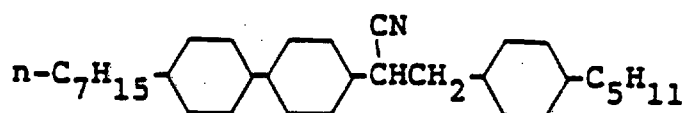
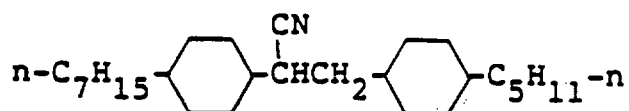
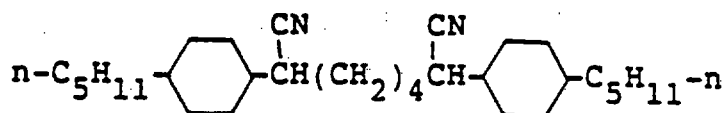
K 41 S_A 46 I



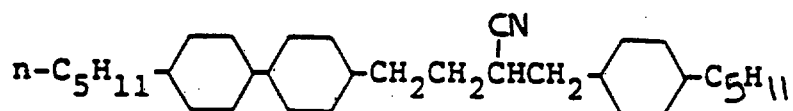
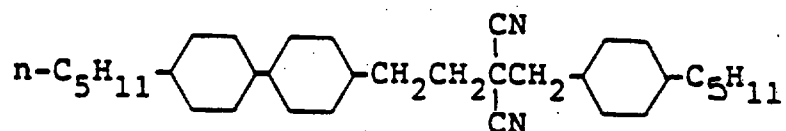
mp 91°C



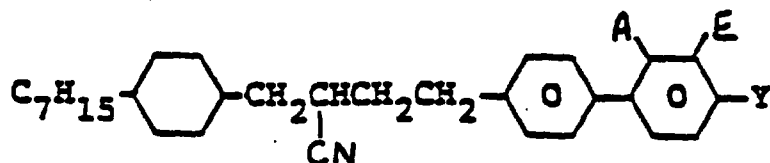
K 127 I

K 15 S_B 88 IK 71.5 S 161 S₂ 162 N 173 IK 47 S_A 66 I

K 106.5 I

K 53 S_B 70 IK 104 (S_B 93) I

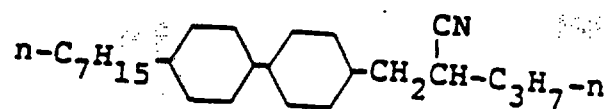
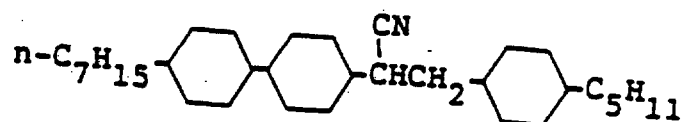
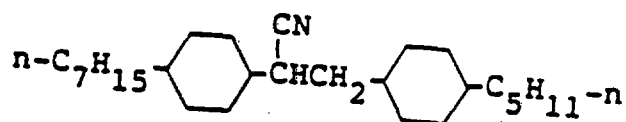
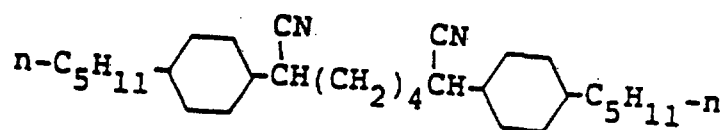
Example 5: A representative example of Route C.



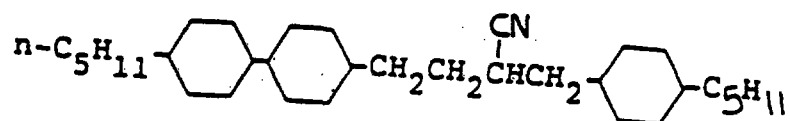
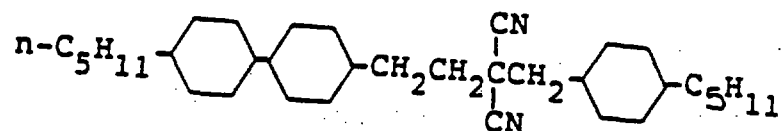
C1 A solution of trans-4-heptylcyclohexyl-carboxylic acid (3) (10 g/0.044 mol) in thionyl chloride (75 ml) and DMF (3 drops) was heated with stirring under reflux for 3 hours. After cooling, the excess thionyl chloride was removed under vacuum. The residue was treated with dry ether (50 ml) and again concentrated under vacuum.

Dry ether (50 ml) was carefully added to lithium aluminium hydride (3.35 g/0.088 mol) under dry nitrogen). To this stirred suspension a solution of the crude acid chloride was added in dry ether (20-30 ml) over one hour at room temperature. The stirred suspension was heated under reflux for 2 hours and then cooled. Water (1.5 ml) was added to destroy excess LiAlH_4 . The mixture was then quenched with dilute HCl (10%). The solution was extracted with ether (3 x 100 ml) and the combined organic extracts washed with water (3 x 50 ml), dried (MgSO_4) and the solvent removed under vacuum. The residue was purified by distillation at $125^\circ\text{C}/0.1$ mm Hg to give the product as a colourless oil. Yield 75%.

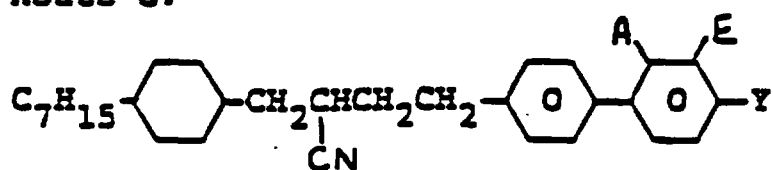
C2 To a stirred solution of alcohol (4) (10 g/0.047 mol) in alcohol free chloroform (47 ml) was added pyridine (7.6 ml/0.094 mol) at 0°C . To this mixture was added tosyl chloride (13.44 g/0.071 mol) in small portions. The mixture was stirred at 0°C for 2 hours and then at room temperature for a further 2 hours. Ether (120 ml) and water (28 ml) were added. The organic layer was separated off and washed successively

K 15 S_B 88 IK 71.5 S 161 S₂ 162 N 173 IK 47 S_A 66 I

K 106.5 I

K 53 S_B 70 IK 104 (S_B 93) I

Example 5: A representative example of Route C.



C1 A solution of trans-4-heptylcyclohexyl-carboxylic acid (3) (10 g/0.044 mol) in thionyl chloride (75 ml) and DMF (3 drops) was heated with stirring under reflux for 3 hours. After cooling, the excess thionyl chloride was removed under vacuum. The residue was treated with dry ether (50 ml) and again concentrated under vacuum.

Dry ether (50 ml) was carefully added to lithium aluminium hydride (3.35 g/0.088 mol) under dry nitrogen). To this stirred suspension a solution of the crude acid chloride was added in dry ether (20-30 ml) over one hour at room temperature. The stirred suspension was heated under reflux for 2 hours and then cooled. Water (1.5 ml) was added to destroy excess LiAlH_4 . The mixture was then quenched with dilute HCl (10%). The solution was extracted with ether (3 x 100 ml) and the combined organic extracts washed with water (3 x 50 ml), dried (MgSO_4) and the solvent removed under vacuum. The residue was purified by distillation at $125^\circ\text{C}/0.1$ mm Hg to give the product as a colourless oil. Yield 75%.

C2 To a stirred solution of alcohol (4) (10 g/0.047 mol) in alcohol free chloroform (47 ml) was added pyridine (7.6 ml/0.094 mol) at 0°C . To this mixture was added tosyl chloride (13.44 g/0.071 mol) in small portions. The mixture was stirred at 0°C for 2 hours and then at room temperature for a further 2 hours. Ether (120 ml) and water (28 ml) were added. The organic layer was separated off and washed successively

with dilute HCl, water 5% NaHCO₃ and water. After drying (MgSO₄) the solvent was removed under vacuum and the crude residue purified by flash-silica chromatography (2% diethyl ether in pet. ether 40/60). The product was a white solid. Yield 67%; m.pt. 33-35°C.

C3 Finely powdered succinic anhydride (10 g/0.1 mol) was thoroughly mixed in a 250 ml flask with powdered AlCl₃ (27 g/0.2 mol). Bromobenzene (37.5 ml/0.36 mol) was added and the mixture stirred and heated at 100-110°C for one hour. Clouds of HCl were given off and the solid dissolved to give a dark red solution. The reaction mixture was cooled and then poured on to ice water containing conc. HCl (30 ml). The mixture was extracted with ethyl acetate (3 x 150 ml). The combined organic extracts were washed with aq. 2M NaOH (3 x 150 ml). The combined aqueous extracts were acidified using conc. HCl. The precipitated solid product was filtered off and dried at the pump. Recrystallisation from ethanol gave the crystalline acid. Yield 64%; m.pt. 141-143°C.

C4 A mixture of mossy zinc (46 g), mercury (II) chloride (3.45 g), conc. HCl (2.3 ml) and water (57 ml) was stirred at room temperature for 5-10 minutes. The solution was decanted off and to the amalgamated zinc was added water (30 ml), conc. HCl (80 ml), glacial acetic acid (2 ml), toluene (40 ml) and β -(p-bromobenzoyl)propanoic acid (20 g/0.078 mol). The mixture was stirred and heated under reflux for 9 hours. After cooling, the organic layer was separated off, washed with water and dried (MgSO₄). After filtration the solvent was removed under vacuum and the residue distilled. The product was collected at 146°C/0.5 mmHg. Yield 55%.

C5 A solution of acid (7) (10 g/0.04 mol) in thionyl chloride (100 ml) containing DMF (a few drops) was stirred overnight at room temperature. The thionyl chloride was then removed under vacuum to give the crude acid chloride. The acid chloride was dissolved in diglyme (20 ml) and this solution was added slowly to stirred aqueous ammonia (35%, 200 ml). The resultant mixture was stirred for a further 30 minutes. The solid was filtered and washed with cold water. After drying (vacuum oven, 50°C) a sample was recrystallised from pet. ether 40/60 and ethyl acetate. The bulk of the material was carried on to the next step without further purification. Yield 83%.

C6 To a stirred solution of amide (8) (7.0 g/0.029 mol) in dry DMF (170 ml) was added a solution of thionyl chloride (21/0.29 mol) in dry DMF (170 ml) dropwise at room temperature. It was then poured onto water (500 ml) and the product extracted with ether (3 x 100 ml). The combined organic extracts were washed with water, aqueous NaHCO_3 solution, water and then dried (MgSO_4). After removal of the solvent under vacuum the dark residue was distilled under vacuum. The product was collected at 150-160°C/0.1 mm Hg. Yield 83%.

C7 To a stirred solution of di-isopropylamine (4.7 ml/0.035 mol) in dry THF (25 ml) under dry nitrogen at 0°C, was added n-BuLi (13.6 ml of 2.5 M solution/0.034 mol). After stirring for 30 minutes at 0°C, the temperature was lowered to -78°C and nitrile (9) (6 g/0.027 mol) was added dropwise. The mixture was stirred for a further one hour at -78°C. A solution of tosylate (5) (10.1 g/0.027 mol) in dry THF (8 ml) was then added dropwise and the mixture stirred for one hour at -78°C and then allowed to warm up to room temperature. After stirring overnight the reaction was quenched with

aqueous NH_4Cl solution and extracted with ether (3 x 50 ml). The combined organic extracts were washed with water and sat. brine and dried (MgSO_4). The solvent was removed under vacuum and the residue subjected to flash-silica chromatography (eluent 5% diethyl ether in pet. ether 40/60). The product was a crystalline solid. Yield 24%.

C8 A solution of 4-pentylphenylboronic acid (0.7 g/3.15 ml) was added to a stirred mixture of nitrile (10) 1 g/2.39 mmol) and tetrakis(triphenylphosphine) palladium (0) (0.15 g/0.13 mmol) in benzene (30 ml) and 2M Na_2CO_3 solution (30 ml) at room temperature and under dry nitrogen. The stirred mixture was heated under reflux and the reaction monitored by TLC. Once complete, the mixture was cooled and diluted with some ether and some water. The mixture was extracted with ether (3 x 50 ml). The combined organic extracts were washed with brine and dried (MgSO_4). The solvent was removed under vacuum and the residue purified by flash-silica chromatography (eluent 40% dichloromethane in pet. ether 40/60). The solid product was recrystallised from hexane. Yield 83%. The product prepared using 4-pentylphenylboronic acid was 1-(trans-4-Heptylcyclohexyl)-2-cyano-4-(4-pentylbiphenyl-4'-yl)-butane (compound 1a of Table 3).

The following compounds were similarly prepared using different boronic acids :

1-(trans-4-Heptylcyclohexyl)-2-cyano-4-(4-hexoxybiphenyl-4'-yl)butane (compound 1b of Table 3); purification by flash-silica chromatography (eluent 40% dichloromethane in pet. ether 40/60) followed by recrystallisation from hexane/ethyl acetate. Yield 97%.

1-(trans-4-Heptylcyclohexyl)-2-cyano-4-(4-octoxybiphenyl-4'-yl)butane (compound 1c of Table 3); purification by flash-silica chromatography (eluent 30% dichloromethane in pet. ether 40/60) followed by recrystallisation from pet. ether 40/60. Yield 26%.

1-(trans-4-Heptylcyclohexyl)-2-cyano-4-(4-decoxybiphenyl-4'-yl)butane (compound 1d of Table 3); purification by flash-silica chromatography (eluent 30% dichloromethane in pet. ether 40/60) followed by recrystallisation from pet. ether 40/60. Yield 33%.

1-(trans-4-Heptylcyclohexyl)-2-cyano-4-(2-fluoro-4-octoxybiphenyl-4'-yl)butane (compound 1e of Table 3); purification by flash-silica chromatography (eluent 30% dichloromethane in pet. ether 40/60) followed by recrystallisation from pet. ether 40/60. Yield 20%.

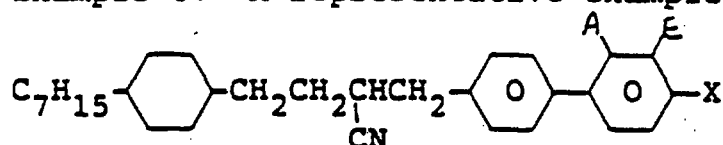
1-(trans-4-Heptylcyclohexyl)-2-cyano-4-(2,3-difluoro-4-octoxybiphenyl-4'-yl)butane (compound 1f of Table 3); purification by flash-silica chromatography (eluent 30% dichloromethane in pet. ether 40/60) followed by recrystallisation from ethanol. Yield 33%.

Table 3 shows a list of the derivatives prepared and their respective transition temperatures.

Table 3 Transition Temperatures of Compounds 1a-f

Compound	Y	A	E	Transition Temperatures/°C
1a	-C ₅ H ₁₁	H	H	K 86.5 S _A 93.0 I
1b	-OC ₆ H ₁₃	H	H	K 116.0 (S _A 105.5) I
1c	-OC ₈ H ₁₇	H	H	K 115.8 S _A 116.9 I
1d	-OC ₁₀ H ₂₁	H	H	K 109.5 S _A 113.6 I
1e	-OC ₈ H ₁₇	F	H	K 63.0 S _A 76.0 I
1f	-OC ₈ H ₁₇	F	F	K 46.7 S _A 61.5 I

Example 6: A representative example of Route D.



D1 This method followed that used in step C1. The product was purified by distillation, b.pt. 140-150°C/0.25 mmHg. Yield 70%.

D2 This method followed that used in step C2. The product was purified by flash-silica chromatography (eluent 2% diethyl ether in pet. ether 40/60). Yield 92%.

D3 A stirred solution of p-bromobenzaldehyde (10 g/0.05 mol) and malonic acid (11.44 g/0.11 mol) in pyridine (25 ml) containing piperidine (0.4 ml) was heated at 100-110°C for 3 hours. After cooling, the solution was poured onto water (200 ml) containing conc. HCl (25 ml) with stirring. The precipitated product was filtered, washed with water and dried. The product was recrystallised from ethanol, m.pt. 254-256°C. Yield 98%.

D4 The method followed that used in step C5. The product was purified by crystallisation from ethyl acetate/ethanol, m.pt. 206-209°C. Yield 97%.

D5 A solution of amide (16) (7.6 g/0.034 mol) in ethanol/THF (200 ml) containing PtO₂ catalyst (0.2 g) was stirred under hydrogen until the uptake of the gas had ceased. The catalyst was filtered off and the solvent removed under vacuum. The product was purified by recrystallisation from ethyl acetate, m.pt. 138-138°C. Yield 95%.

D6 The method followed that used in step C6. The product was purified by distillation, b.pt. 135°C/0.1 mm Hg. Yield 83%.

D7 The method followed that used in step C7. The product was purified by flash-silica chromatography (eluent 5% diethyl ether in pet. ether 40/60). Yield 54%.

D8 The method followed that used in step C8. The product was purified by flash-silica chromatography (eluent 30% dichloromethane in pet. ether 40/60) followed by recrystallisation from hexane. Yield 91%. The compound prepared using 4-pentylphenylboronic acid was 1-(4-trans-Heptylcyclohexyl)-3-cyano-4-(4-pentylbiphenyl -4'-yl)butane (compound 2a of Table 4).

The following systems were similarly prepared using different boronic acids.

1-(4-trans-Heptylcyclohexyl)-3-cyano-4-(4-hexoxybiphenyl-4'-yl)butane (compound 2b of Table 4); purification by flash-silica chromatography (eluent 40% dichloromethane in pet. ether 40/60) followed by recrystallisation from ethyl acetate/pet. ether 40/60; yield 87%.

1-(4-trans-4-Heptylcyclohexyl)-3-cyano-4-(4-octoxybiphenyl-4'-yl)-butane (compound 2c of Table 4); purification by flash-silica chromatography (eluent 30% dichloromethane in pet. ether 40/60 followed by recrystallisation from ethanol/ethyl acetate. Yield 98%.

1-(4-trans-4-Heptylcyclohexyl)-3-cyano-4-(4-decoxybiphenyl-4'-yl)-butane (compound 2d of Table 4); purification by flash-silica chromatography (eluent 35% dichloromethane in pet. ether 40/60) followed by recrystallisation from ethanol/ethyl acetate. Yield 73%.

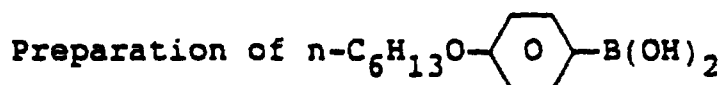
1-(4-trans-Heptylcyclohexyl)-3-cyano-4-(2-fluoro-4-octoxybiphenyl-4'-yl)butane (compound 2e of Table 4); purification by flash-silica chromatography (eluent 35% dichloromethane in pet. ether 40/60 followed by recrystallisation from ethanol/ethyl acetate. Yield 66%.

1-(4-trans-Heptylcyclohexyl)-3-cyano-4-(2,3-difluoro-4-octoxybiphenyl-4'-yl)butane (compound 2f of Table 4); purification by flash-silica chromatography (eluent 35% dichloromethane in pet. ether 40/60 followed by recrystallisation from ethanol/ethyl acetate or acetone. Yield 58%.

Table 4 shows a list of the derivatives prepared and their respective transition temperatures.

Table 4 Transition Temperatures of Compounds 2a-f

Compound	X	A	E	Transition Temperatures/°C
2a	-C ₅ H ₁₁	H	H	K 98.0 (S _A 91.7) I
2b	-OC ₆ H ₁₃	H	H	K 113.5 S _A 119.5 I
2c	-OC ₈ H ₁₇	H	H	K 110.0 S _A 116.4 I
2d	-OC ₁₀ H ₂₁	H	H	K 106.3 S _A 113.8 I
2e	-OC ₈ H ₁₇	F	H	K 72.9 S _C 81 S _A 86 I
2f	-OC ₈ H ₁₇	F	F	K 92.2 S _A 94.5 I

Example 7 A representative Example of Route G

G1 A solution of 1-bromohexane (60 g) in acetone (150 ml) was added dropwise to a stirred mixture of 4-bromophenol (71 g) and K₂CO₃ (120 g) in acetone (600 ml) at room temperature. The stirred mixture was heated under reflux for 43 hr (i.e. until glc revealed complete reaction). The product was extracted into ether twice, and the combined ethereal extracts were washed with water, 5% NaOH water and dried (MgSO₄). The solvent was removed in vacuo and the residue was distilled (bp = 100-110°C at 0.1 mm Hg) to yield a colourless liquid (79.4 g, 86%).

G2 A solution of the Grignard Reagent prepared from G1 (72 g) and Mg (7.75 g) in dry THF (250 ml) was added dropwise to a stirred, cooled (-78°C) solution of tri-isopropyl borate (109.1 g) in dry THF (40 ml) under dry N₂. The stirred mixture was allowed to warm to room temperature overnight and stirred with 10% HCl (320

ml) at room temperature for 1 hr. The product was extracted into ether twice, and the combined ethereal extracts were washed with water and dried (MgSO_4). Solvent was removed in vacuo to yield a colourless solid (61.2 g, 99%) mp = 80-85°C.

An example of the use of a compound of Formula I in a liquid crystal material and device embodying the present invention will now be described with reference to Figure 6.

In Figure 6, a liquid crystal cell comprises a layer 1 of liquid crystal material exhibiting a chiral smectic phase sandwiched between a glass slide 2 having a transparent conducting layer 3 on its surface, e.g. of tin oxide or indium oxide, and a glass slide 4 having a transparent conducting layer 5 on its surface. The slides 2, 4 bearing the layers 3,5 are respectively coated by films 6,7 of a polyimide polymer. Prior to construction of the cell the films 6 and 7 are rubbed with a soft tissue in a given direction, the rubbing directions being arranged parallel upon construction of the cell. The spacer 8 e.g. of polymethyl methacrylate, separates the slides 2,4 to the required distance, e.g. 5 microns.

The liquid crystal material 1 is introduced between the slides 2,4 by filling the space between the slides 2,4 and spacer 8 and sealing the spacer 8 in a vacuum in a known way. Preferably the liquid crystal material is in the smectic A, nematic or isotropic liquid phase (obtained by heating the material) when it is introduced between the slides 2,4 to facilitate alignment of the liquid crystal molecules with the rubbing directions on the slides 2,4.

A polarizer 9 is arranged with its polarization axis parallel to the rubbing direction on the films 6,7 and an analyzer (crossed polarizer) 10 is arranged with its polarization axis perpendicular to that rubbing direction.

When a square wave voltage (from a conventional source not shown) varying between about +10 volts and -10 volts is applied across the cell by making contact with the layers 3 and 5 the cell is rapidly switched upon the change in sign of the voltage between a dark state and a light state as explained above.

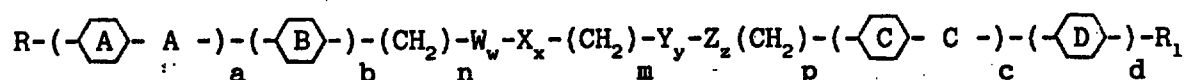
In an alternative device (not shown) based on the cell construction shown in Figure 6 the layers 3 and 5 may be selectively shaped in a known way, e.g. by photoetching or deposition through a mask, e.g. to provide one or more display symbols, e.g. letters, numerals, words or graphics and the like as conventionally seen on displays. The electrode portions formed thereby may be addressed in a variety of ways which include multiplexed operation.

The liquid crystal material 1 may be any one of the mixtures described in the preceding examples.

CLAIMS

1. A ferroelectric liquid crystal mixture including at least one compound of formula I:

Formula I



wherein R and R₁ are independently C₁-C₁₂ alkyl, alkoxy, perfluoroalkyl or perfluoroalkoxy;

rings A, B, C and D are independently phenyl, which may carry one or two halogen substituents, trans-cyclohexyl, or (2,2,2) bicyclooctyl, each of a, b, c or d being independently 0 or 1 provided (a+b+c+d) is 2 or 3 and further that c+d = 0 only when A and B are both cyclohexyl;

links A and C are independently a single bond, CH₂CH₂, COO, OOC, CH₂O or OCH₂;

n, m and p are independently 0 or an integer 1 to 4 provided (n+m+p) is not 0 except when the linking group between B and C is HC=C(CN)-; W and Z are independently selected from -CH=C(CN)- and -C(CN)=CH-;



X and Y are independently selected from $-\text{CHCN}$ and $-\text{C}(\text{CN})_2-$;

w, x, y and z are 0 or 1, provided that w and z are 0 if x and/or y are 1, and further provided that at least one of w, x, y and z is 1.

2. A mixture according to claim 1, wherein R and R_1 are n-alkyl or n-alkoxy or asymmetrically substituted alkyl or alkoxy.

3. A mixture according to claim 1, wherein rings A and B are cyclohexyl.

4. A mixture according to claim 1, wherein if rings C and D are halogen substituted phenyl the halogen is fluorine.

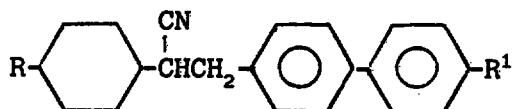
5. A mixture according to claim 1, wherein the links A and C are single bonds.

6. A mixture according to claim 1, wherein if c and d are 0, R_1 is alkyl.

7. A mixture according to claim 1, wherein only ring A is (2,2,2,) bicyclooctyl.

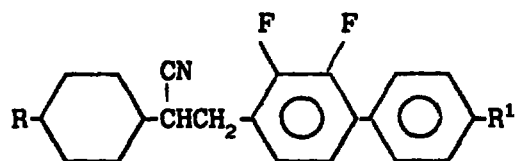


8. A mixture according to claim 1, wherein n, w, y, z and $p = 0$; $x, m = 1$ and $X = \text{CHCN}$.
9. A mixture according to claim 1, wherein w, m, y, z and $p = 0$, $n, x = 1$ and $X = \text{CHCN}$.
10. A mixture according to claim 1, wherein $w, m, y, z, p = 0$; $n, x = 1$, $X = \text{C}(\text{CN})_2$.
11. A mixture according to claim 1, wherein $n, x, m, y, z, p = 0$; $w = 1$; $W = -\text{CH}=\text{C}(\text{CN})-$.
12. A mixture according to claim 1, wherein $w, y, z, p = 0$; $x, m = 1$; $n = 2$; $X = \text{CHCN}$ or $\text{C}(\text{CN})_2$.
13. A mixture according to claim 1, wherein $n, w, z, p = 0$; $x, y = 1$; $m = 4$; $X, Y = \text{CHCN}$.
14. A mixture according to claim 1 wherein the compound of formula I is a compound given by the formulae IA1, IA4, IA5, IB2, IB3 or IB4 :

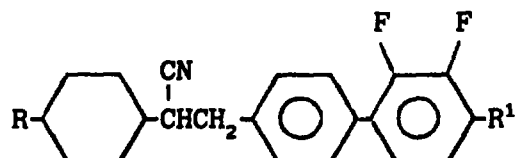


IA1

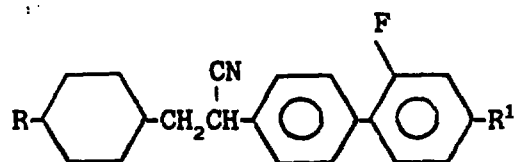




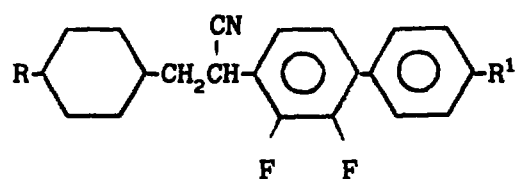
IA4



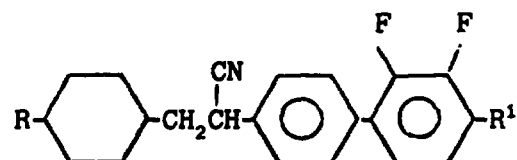
IA5



IB2

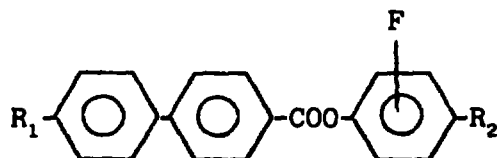


IB3



IB4

15. A mixture according to claim 1, wherein the mixture additionally contains at least one compound of formula IIA :

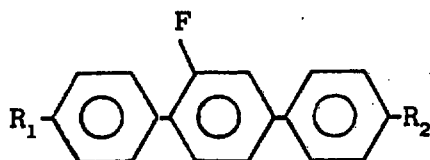


IIA

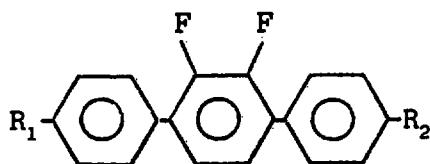
wherein R_1 and R_2 are independently C_2 - C_{12} alkyl or alkoxy.



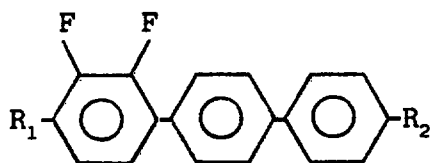
16. A mixture according to claim 1, wherein the mixture additionally contains at least one compound of formula IIB1, formula IIB2 or formula IIB3:



IIB1



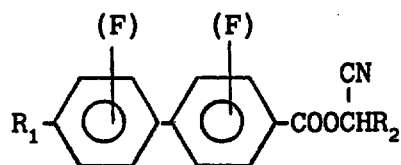
IIB2



IIB3

wherein R_1 and R_2 are independently C_2-C_{12} alkyl or alkoxy.

17. A mixture according to claim 15 or claim 16, wherein the mixture alternatively or additionally contains at least one compound of formula III :



III

wherein R_1 may be C_{1-12} n-alkyl or n-alkoxy and R_2 may be C_{1-15} alkyl, or n-alkyl or a branched chain or optically active alkyl, (F) indicates that the rings indicated may carry a lateral fluorine substituent.



18. A mixture according to any one of claims 1 and 15 to 17, wherein the mixture contains up to 95 wt% of compounds of formula IIA or IIB, where IIB refers to any combination of IIB1, IIB2 and IIB3, up to 15 wt% of a compound of formula III and up to 25 wt% of a compound of formula I, the total being 100 wt%.

19. A liquid crystal electrooptical display device incorporating a mixture as claimed in claim 1.

