Tetrahedron Vol. 46, No. 20, pp 7069-7080, 1990
Printed in Great Britain

0040-4020/90 $3.00+.00

SYNTHESIS AND PROPERTIES OF PARTIALLY FLUORINATED 4-ALKYL-4'-CYANOBIPHENYLS - PART II. 4-ALKYL-4'-CYANO-2',3',5',6'-TETRAFLUOROBIPHENYLS.¶

Leslie D. Field*, Trevor W. Hambley and Gregory K. Pierens

Department of Chemistry,
University of Sydney, N.S.W., Australia, 2006.

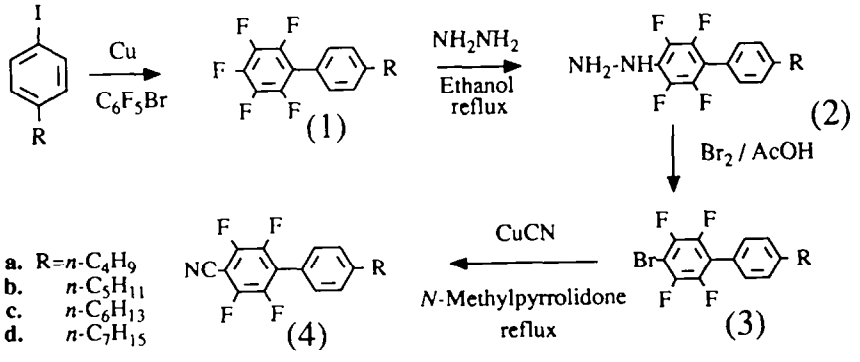
(*Received in UK 9 July* 1990)

A general synthetic route to 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls has been developed and used to prepare compounds with unbranched alkyl chains ranging from 4 to 7 carbon atoms. The compounds were characterised by ^{19}F, ^{13}C and ^{1}H NMR spectroscopy. One member of the series, 4-butyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl, was characterised crystallographically at 147 K.

In a continuing project involving liquid crystalline materials and components of liquid crystalline mixtures, we have synthesised a range of substituted 4-alkyl-4'-cyanobiphenyls. In a previous paper[1] we described the synthesis and properties of a number of partially fluorinated 4-alkyl-4'-cyanobiphenyls with a view to using these as "proton-depleted" components of liquid crystalline mixtures for use as potential spectroscopic solvents.[1] We report here the synthesis and properties of a series of 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls.¶

Results and Discussion.

The synthesis of the 4-alkyl-4'-cyanobiphenyl framework requires that three critical bonds be made *(i)* the aryl-aryl bond, *(ii)* the aryl-alkyl bond and *(iii)* the aryl-C≡N bond. In the synthesis of 4'-alkyl-4-cyano-2',3',5',6'-tetrafluorobiphenyls,[1] the fluorinated ring of 4-amino-2',3',5',6'-tetrafluorobiphenyl was alklated with an alkyllithium reagent and the amino group subsequently elaborated to the required cyano group. This approach is inappropriate for the synthesis of 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls (where the cyano group is substituted on the fluorinated aromatic ring) and the synthesis proceeded from commercially available 4-alkylanilines (Scheme 1).



Scheme 1.

The 4-alkylanilines were converted to the corresponding iodides using standard procedures and the aryl-aryl bond was made by coupling the iodide with bromopentafluorobenzene over copper powder at high temperature. The unsymmetrical coupling product, 4-alkyl-2',3',4',5',6'-pentafluorobiphenyl, was the major component of the product mixture (>60%) and was easily isolated by fractional distillation. An $-NH-NH_2$ group was introduced into the 4-position of the fluorinated aromatic ring by reaction with hydrazine hydrate in refluxing absolute ethanol. The hydrazino compound was converted to the bromide and the required $-C{\equiv}N$ group was introduced by reaction with copper(I) cyanide (Scheme 1). The conversion of the 4-alkyl-4'-hydrazino-2',3',5',6'-tetrafluorobiphenyl to the nitrile typically proceeded in 50-70% isolated yield. 4-Alkyl-2',3',5',6'-tetrafluorobiphenyls **(5)** (loss of the $-NH-NH_2$ group with ring protonation) were consistent byproducts in the conversion of **(2)** to **(3)**.

Physical properties of 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls. 4-Alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls containing 4, 5, 6 and 7 membered *n*-alkyl chains were synthesised in the same manner (according to Scheme 1). All are colourless crystalline solids at room temperature with melting points close to those (±15°C) of the corresponding fully protonated analogues (Table 1). None of the compounds exhibited a liquid crystalline phase which could be detected by slow melting and solidification of the pure materials. The melting points are 20-50°C less than the corresponding isomeric 4'-alkyl-4-cyano-2',3',5',6'-tetrafluorobiphenyls.[1]

Table 1. MELTING POINTS[a] OF 4-ALKYL-4'-CYANO-2',3',5',6'-TETRAFLUOROBIPHENYLS AND THEIR PROTONATED ANALOGUES.

Alkyl chain	Fully protonated[b] °C	Partially fluorinated °C	
n-Butyl	46 (46-16)[c]	34-35	**(4a)**
n-Pentyl	23[d] (23-35)	7-9	**(4b)**
n-Hexyl	15[d] (15-30)	21-23	**(4c)**
n-Heptyl	29[d] (29-43)	28-29	**(4d)**

a. solid → isotropic transition temperature.
b. From ref. 2, liquid crystal range (°C) is in parenthesis.
c. From ref. 3.
d. solid → nematic transition temperature.

NMR spectroscopy. The products of the syntheses as well as various key intermediates in the synthetic schemes were characterised routinely by ^{19}F, ^{1}H and ^{13}C NMR spectroscopy. The ^{19}F NMR spectra of the 4-alkyl-4'-substituted-2',3',5',6'-tetrafluorobiphenyls (Table 2) exhibited resonances in the expected region for ^{19}F in polyfluorinated aromatic compounds. For all of the 4-alkyl-2',3',4',5',6'-tetrafluorobiphenyls **(1)** synthesised, the ^{19}F NMR spectra appeared as three multiplets for the three chemically distinct fluorine enviroments. The ^{19}F NMR spectra of the hydrazino substituted compounds **(2)** all exhibit the usual AA'XX' coupling pattern with the fluorines 3' and 5' (ortho to the to the nitrogen substitutent) significantly more shielded than the other fluorine nuclei in the molecule. The 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls **(4)** and 4-alkyl-2',3',5',6'-tetrafluorobiphenyls **(5)** exhibited two sets of multiplets in the ^{19}F spectrum with a typical AA'XX' coupling pattern.

Table 2. ^{19}F NMR SHIFTS[a] OF 4-R-4'-X-2',3',5',6'-TETRAFLUOROBIPHENYLS.

Compound	X	R	$\delta^{19}F$ F2',F6'	$\delta^{19}F$ F3',F5'	$\delta^{19}F$ F4'
1a	F	*n*-Butyl	-139.9	-159.0	-152.8
2a	NH_2NH_2	*n*-Butyl	-142.2	-155.7	-
4a	CN	*n*-Butyl	-136.8	-129.3	-
5a	H	*n*-Butyl	-135.9	-140.5	-
1b	F	*n*-Pentyl	-139.9	-159.1	-152.8
2b	NH_2NH_2	*n*-Pentyl	-142.1	-155.7	-
4b	CN	*n*-Pentyl	-138.8	-129.4	-
5b	H	*n*-Pentyl	-136.0	-140.6	-
1c	F	*n*-Hexyl	-139.9	-159.0	-152.7
2c	NH_2NH_2	*n*-Hexyl	-142.1	-155.7	-
4c	CN	*n*-Hexyl	-136.7	-129.3	-
5c	H	*n*-Hexyl	-135.9	-140.5	-
1d	F	*n*-Heptyl	-139.9	-159.0	-152.7
2d	NH_2NH_2	*n*-Heptyl	-142.1	-155.7	-
4d	CN	*n*-Heptyl	-136.8	-129.4	-
5d	H	*n*-Heptyl	-135.9	-140.5	-

a. ^{19}F NMR shifts are referenced to neat external C_6F_6 taken as δ-163.0 ppm.

The ^{13}C NMR spectra of the 4-alkyl-4'-substituted-2',3',5',6'-tetrafluorobiphenyls (Tables 3 and 4) exhibited strong resonances for the protonated carbons. ^{13}C resonances of the fluorinated rings were difficult to observe (without ^{19}F decoupling) due to the direct and long range ^{19}F-^{13}C couplings. The fluorinated aromatic carbons appear characteristically 10 to 20 ppm to lower field than the protonated aromatic carbons with one-bond fluorine-carbon splittings of about 250 Hz. The quaternary carbons of the fluorinated aromatic ring appear as narrow triplets (15-20 Hz) due to two-bond coupling to the fluorine nuclei at C2',6' and C3',5' in each ring.

Crystal structure of 4-butyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl (**4a**). Details of the crystal structure will be published elsewhere.[4] An ORTEP plot of the structure of the molecule is given in Figure 1.

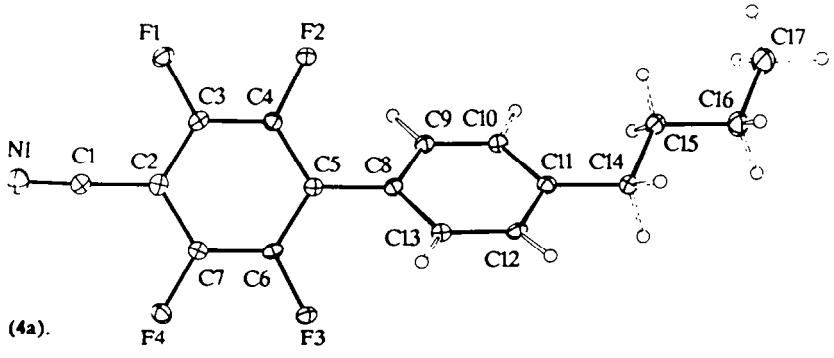
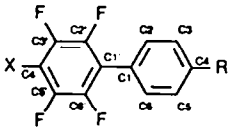


Figure 1.
ORTEP plot of (4a).

The conformation of (**4a**) in the solid state is best described as three linked planar groups – the cyanotetrafluorophenyl ring, the phenyl ring and the butyl sidechain. The butyl group is less planar, as expected since there are no chemical factors disposing it toward planarity, but the C atoms lie within

Table 3. ^{13}C NMR CHEMICAL SHIFTS AND COUPLING CONSTANTS OF FLUORINATED COMPOUNDS[a].

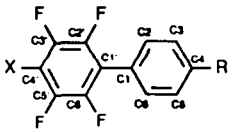


X = -F, -H

Compound	C4' ($^2J_{C-F}$)	C3',C5'[b] ($^1J_{C-F}$)	C2',C6'[b] ($^1J_{C-F}$)	C1' ($^2J_{C-F}$)	C1	C2,C6	C3,C5	C4	
1a	140.3 (225.4)	137.8 (241.5)	144.4 (257.5)	116.0 (17.7)	123.6	128.8	129.9	144.4	C1"-35.5, C2"-C3"-33.4, 22.4, CH_3-13.9.
5a	104.5 (22.6)	146.2 (251.5)	143.8 (241.5)	121.6 (15.7)	124.6	128.6	129.9	144.2	C1"-35.5, C2"-C3"-32.4, 22.4, CH_3-13.9
1b	140.2 (222.2)	137.9 (238.1)	144.3 (246.0)	116.0 (16.4)	123.5	128.7	129.9	144.4	C1"-35.8, C2"-C4"-31.5, 30.9, 22.5, CH_3-14.0
5b	104.47 (22.6)	146.3 (259.9)	143.9 (230.2)	121.6 (15.0)	124.7	128.6	129.9	144.25	C1"-35.8, C2"-C4"-31.6, 30.94, 22.5, CH_3-14.0
1c	140.4 (223.1)	137.9 (239.1)	144.3 (252.7)	116.0 (15.8)	123.5	128.8	130.0	144.4	C1"-35.7, C2"-C5"-31.7, 31.2, 29.0, 22.6, CH_3-14.0
5c	104.5 (21.0)	146.2 (241.7)	143.8 (241.7)	121.6 (15.7)	124.5	128.6	130.0	144.3	C1"-35.6, C2"-C5"-31.7, 31.2, 29.0, 22.6, CH_3-14.0
1d	140.5, (225.4)	137.8 (241.5)	144.3 (249.6)	116.0 (16.1)	123.6	128.8	130.0	144.4	C1"-35.6, C2"-C6"-31.6, 31.3, 29.3, 29.2, 22.8, CH_3-14.0
5d	104.5 (22.6)	146.2 (251.5)	143.9 (231.4)	121.6 (17.8)	124.6	128.6	129.9	144.3	C1"-35.6, C2"-C6"-31.6, 31.3, 29.3, 29.2, 22.7, CH_3-14.0

a. $CDCl_3$ solution, 300K, $CDCl_3$ taken as δ77.0 ppm, coupling constants in Hz.
b. C2',C6'/C3',C5' not conclusively assigned.

Table 4. ^{13}C NMR CHEMICAL SHIFTS AND COUPLING CONSTANTS OF FLUORINATED COMPOUNDS[a].



Compound	C4' ($^2J_{C-F}$)	C3',C5'[b] ($^1J_{C-F}$)	C2',C6'[b] ($^1J_{C-F}$)	C1' ($^2J_{C-F}$)	C1	C2,C6	C3,C5	C4	C≡N	
2a	129.1 (12.6)	138.1 (236.3)	144.3 (244.3)	111.5 (15.7)	124.7	128.6	130.0	143.5	-	C1"-35.4, C2"-C3"-33.4, 22.4, CH_3-13.9
4a	92.48 (18.6)	147.7 (259.2)	143.9 (234.6)	127.3 (13.5)	122.9	128.9	129.8	145.7	107.6	C1"-35.5, C2"-C3"-32.3, 22.4, CH_3-13.7
2b	129.2 (9.5)	138.2 (238.1)	144.5 (246.3)	111.6 (15.8)	124.8	128.6	130.0	143.6	-	C1"-35.7, C2"-C4"-31.5, 30.9, 22.53, CH_3-14.0
4b	92.5 (21.4)	147.6 (260.0)	143.9 (250.0)	127.4 (16.1)	122.9	128.9	129.8	145.8	107.6	C1"-35.6, C2"-C4"-31.5, 30.6, 22.5, CH_3-13.9
2c	129.2 (13.4)	138.1 (235.4)	144.2 (244.7)	111.6 (14.7)	124.8	128.6	130.0	143.6	-	C1"-35.6, C2"-C5"-31.7, 31.2, 29.0, 22.6, CH_3-14.0
4c	92.6 (17.9)	147.5 (261.9)	143.8 (250.0)	127.4 (14.3)	123.0	129.0	129.6	145.8	107.6	C1"-35.7, C2"-C5"-31.7, 31.1, 29.0, 22.6, CH_3-14.0
2d	129.1 (12.9)	138.2 (233.4)	144.2 (241.5)	111.6 (16.1)	124.7	128.6	130.0	143.6	-	C1"-35.8, C2"-C6"-31.6, 31.3, 29.3, 29.2, 22.7, CH_3-14.0
4d	92.4 (19.3)	147.4 (261.9)	143.8 (246.9)	127.3 (18.8)	122.7	128.7	129.8	145.7	107.5	C1"-35.6, C2"-C6"-31.7, 31.1, 29.3, 29.1, 22.6, CH_3-14.0

a. $CDCl_3$ solution, 300K, $CDCl_3$ taken as δ77.0 ppm, coupling constants in Hz.
b. C2',C6'/C3',C5' not conclusively assigned.

0.034 Å of the least-squares plane through them. The butyl group is oriented at 13.4° to the plane of the phenyl group and there is an angle of 40.8° between the tetrafluorophenyl and the phenyl ring. As has been noted previously, the torsional angle between the aryl rings in biphenyls in the solid state depends at least as much on crystal packing forces as on any intramolecular factors, with steric interactions between the 2,6- and 2',6'-substituents providing a lower limit.[5]

The inter-ring C–C bond length, 1.477(4) Å, is shorter than those reported for 2,3,5,6-tetrafluorobiphenyl[6] or 2,3,4,5,6-pentafluorobiphenyl[7] (1.492 and 1.493(3) Å respectively), possibly as a consequence of the lower inter-ring torsion angle. The C–C bonds in the tetrafluorophenyl ring range from 1.373(4) to 1.398(4) Å and in the phenyl group from 1.379(4)–1.403(4) Å. In each case the two shortest bonds are the C2–C3 and C5–C6 bonds although the differences are of marginal significance. The C–F bond lengths (av. 1.339 Å), are similar to those in the aforementioned compounds.

Figure 2 shows the basic motif of the structure – a pair of molecules stacked antiparallel (head-to-tail) in which the phenyl ring and the tetrafluorophenyl rings almost exactly overly each other. Closest carbon–carbon contacts are 3.388 Å within the pairs and 3.380 Å between the pairs. The stacks of molecules are aligned and the stacks make head-to-tail contacts in the direction of the long axes of the molecules.

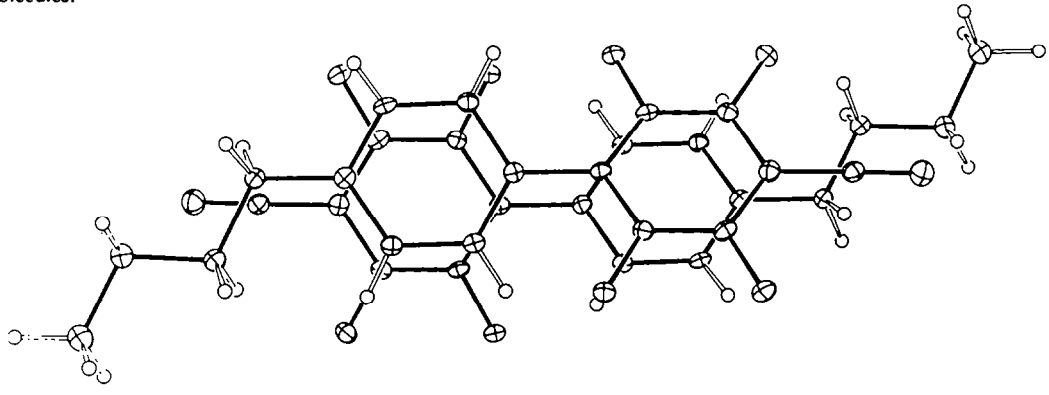


Figure 2. **Packing of molecules of 4-butyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl (4a) within the unit cell.**

A similar alternating head-to-tail stacking of C_6H_5 and C_6F_5 groups has been noted in the structure of 2,3,4,5,6-pentafluorobiphenyl[7] and this has been attributed to the formation of donor–acceptor pairs through π-orbital interactions between electron deficient and electron rich aromatic rings. In the crystal structure of 4-butyl-4'-cyanobiphenyl,[3] the molecules also align in antiparallel pairs in the unit cell, however the paired molecules are offset so that the butyl-substituted rings are overlapped. The strong interaction between the fluorinated and non-fluorinated aromatic rings undoubtedly stabilises the solid state structure of **(4a)** and this would be a factor contributing to the lack of a stable mesophase on melting of the solid or cooling of the liquid phase.

Conclusions.

A general synthetic route to 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls has been developed and used to prepare compounds with *n*-alkyl chains ranging from 4 to 7 carbon atoms. The approach can be varied easily to introduce any alkyl substituent via the appropriate 4-alkylaniline. The 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls synthesised are low melting crystalline solids which melt at temperatures close to those of the corresponding fully protonated analogues. None of the pure 4-alkyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyls synthesised gave rise to a liquid crystalline phase on melting.

The structure of 4-butyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl in the crystalline state shows that the molecules stack in antiparallel pairs with the phenyl ring and the tetrafluorophenyl rings almost exactly overlaying each other. The angle between the tetrafluorophenyl ring and the phenyl ring is 40.8°.

Acknowledgement. We gratefully acknowledge financial support from the Australian Research Council.

Experimental Section.

X-ray crystallography. Crystals of **(4a)** are orthorhombic, space group $P2_12_12_1$, a = 7.280(4), b = 11.253(3), c = 17.255(5) Å, V = 1413.6 Å^{-3}, Z = 4. Data were collected on an Enraf-Nonius CAD4-F diffractometer with MoKα radiation. The structure was refined to an R value of 0.036 for 1206 observed reflections.

Synthesis of Compounds. Ethyl acetate and light petroleum (bp 60-70°C) were distilled prior to use. Bromopentafluorobenzene, 4-butylaniline, 4-pentylaniline, 4-hexylaniline and 4-heptylaniline were obtained from Aldrich and distilled prior to use. Chromatography was performed on Merck flash silica (230-400 mesh). Ether was dried over sodium wire, and copper cyanide was prepared according to literature procedures.[8] NMR spectra were recorded in $CDCl_3$ solution at 300K unless otherwise noted. ^1H (400.1 MHz) and ^{13}C (100.6 MHz) NMR spectra were recorded on a Bruker WM-400 spectrometer and were referenced to residual solvent resonances. ^{19}F (376.3 MHz) NMR spectra were recorded on a Varian XL-400 spectrometer and were referenced to external neat C_6F_6 (taken as -163.0 ppm).

4-Butyl-2',3',4',5',6'-pentafluorobiphenyl (1a). A mixture of 4-butyliodobenzene (2.1g, 8.1 mmol), bromopentafluorobenzene (2.0g, 8.1 mmol) and copper powder (2g) was heated in a stainless steel reaction bomb at 200°C for 15 hours. The bomb was cooled and the contents extracted exhaustively with ether. The extracts were combined, washed with water, then brine and dried over anhydrous sodium sulfate. The solvent was removed to give a crude brown product which was purified by distillation (Kugelrohr). Decafluorobiphenyl sublimed initially (100°C/1 mm) and then **(1a)** distilled as a colourless liquid (160°C/1 mm) which solidified on cooling. 4-Butyl-2',3',4',5',6'-pentafluorobiphenyl was obtained as a white crystalline solid (1.47g, 61%) mp: 62-63°C. ^1H NMR δ7.35, m, 2H, Ar-H3' Ar-H5'; 7.31, m, 2H, Ar-H2' Ar-H6'; 2.68, t, 2H, Ar-CH_2; 1.67, m, 2H, Ar-CH_2-CH_2; 1.42, m, 2H, Ar-$(CH_2)_2$-CH_2; 0.96, t, 3H, Ar-$(CH_2)_3$-CH_3. IR (KBr disc) 2958(w), 2931(m), 2863(w), 1613(w), 1568(w), 1528(m), 1513(s), 1492(s), 1410(m), 1200(w), 1064(m), 983(s), 958(m), 834(m), 765(m). Anal. calcd. for $C_{16}H_{13}F_5$: C, 63.99%; H, 4.36%. Found: C, 64.0%; H, 4.3%.

4-Butyl-4'-hydrazino-2',3',5',6'-tetrafluorobiphenyl (2a). A solution of 4-butyl-2',3',4',5',6'-pentafluorobiphenyl **(1a)** (1.45g, 4.8 mmol) and hydrazine hydrate (2 ml) in absolute ethanol (10 ml) was heated under reflux for 16 hours. The solvent was removed and the residue was extracted with ether. The combined extracts were dried and the solvent removed to give a crude product which was recrystallized from light petroleum. 4-Butyl-4'-hydrazino-2',3',5',6'-pentafluorobiphenyl **(2a)** was obtained as a pale yellow crystalline solid (1.48g, 98%) which was used without further purification for the preparation of 4-butyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl. ^{1}H NMR δ7.35, m, 2H, Ar-H3' Ar-H5'; 7.28, m, 2H, Ar-H2' Ar-H6'; 5.33, 1H, -NH-; 4.03, 2H, $-NH_2$; 2.67, t, 2H, Ar-CH_2; 1.65, m, 2H, Ar-CH_2-CH_2; 1.41, m, 2H, Ar-$(CH_2)_2$-CH_2; 0.95, t, 3H, Ar-$(CH_2)_3$-CH_3.

4-Butyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl (4a). 4-Butyl-4'-hydrazino-2',3',5',6'-pentafluorobiphenyl **(2a)** (1.48g, 4.7 mmol) was dissolved in glacial acetic acid (10 ml) and a solution of bromine in glacial acetic acid (30% w/w), was added slowly until the colour of bromine persisted and a further aliquot (20% of the volume) was added. The solution was stirred at room temperature for 2 hours, poured into water (50 ml) and extracted with ether. The combined extracts were washed successively with solutions of sodium carbonate and sodium bisulfite. The extracts were dried and the solvent removed to give a brown solid which was dissolved in freshly distilled *N*-methylpyrrolidone (20 ml). Copper(I) cyanide (0.55g, 1.3 eqiv.) was added and the solution was refluxed for 2 hours. The reaction mixture was cooled and poured into a solution of iron(III) chloride (4g of $FeCl_3$ in water 60 ml), then sulfuric acid (18 M, 2 ml) was added and the mixture extracted with ether. The combined extracts were dried and the solvent removed to give a brown oil which was filtered through a plug of silica using ethyl acetate/light petroleum (5:95 v/v) as eluent. The crude product was purified by radial chromatography using light petroleum as eluent and recrystallised from light petroleum to give 4-butyl-4'-cyano-2',3',5',6'-pentafluorobiphenyl **(4a)**, as a yellow crystalline solid (0.72g, 54% with respect to **(2a)**) mp: 34-35°C. ^{1}H NMR δ7.39, m, 2H, Ar-H3 Ar-H5; 7.35, m, 2H, Ar-H2 Ar-H6; 2.69, t, 2H, Ar-CH_2; 1.67, m, 2H, Ar-CH_2-CH_2; 1.42, m, 2H, Ar-$(CH_2)_2$-CH_2; 0.97, t, 3H, Ar-$(CH_2)_3$-CH_3. IR (KBr disc) 2967(w), 2957(w), 2936(w), 2873(w), 2241(m, -C≡N), 1649(m), 1609(w), 1491(s), 1469(m), 1409(m), 1317(m), 1175(m), 989(s), 836(m), 774(m). Mass Spectrum: *m/z* 308(M+1, 6%), 307(M^+, 28), 265(58), 264(100), 245(8), 244(32), 51(8), 43(27), 41(13), 39(19). High resolution mass spectrum calculated for $C_{17}H_{13}F_4N$: 307.0983, found: 307.0992. Anal. calcd. for $C_{17}H_{13}F_4N$: C, 66.44%; H, 4.26%; N, 4.55%. Found C, 66.4%; H, 4.2%; N, 4.5%.

4-Butyl-2',3',5',6'-tetrafluorobiphenyl **(5a)** was isolated as an additional product as a white solid (0.38g, 29% with respect to **(2a)**) mp: 31-32°C. ^{1}H NMR δ7.38, m, 2H, Ar-H3 Ar-H5; 7.31, m, 2H, Ar-H2' Ar-H6'; 7.05, m, Ar-H4'; 2.69, t, 2H, Ar-CH_2; 1.67, m, 2H, Ar-CH_2-CH_2; 1.42, m, 2H, Ar-$(CH_2)_2$-CH_2; 0.96, t, 3H, Ar-$(CH_2)_3$-CH_3. IR (KBr disc) 2957(w), 2929(m), 2852(w), 1644(w), 1612(w), 1569(m), 1495(s), 1488(s), 1453(s), 1409(m), 1289(m), 1169(m), 1150(m), 925(s), 879(w), 829(s), 777(m). Mass Spectrum: *m/z* 283(M+1, 5%), 282(M^+, 24), 265(7), 264(13), 240(32), 239(100), 219(35), 51(7), 43(11), 41(9), 39(10). High-resolution mass spectrum calculated for $C_{16}H_{14}F_4$: 282.1031, found 282.1039.

4-Pentyl-2',3',4',5',6'-pentafluorobiphenyl (1b). A mixture of 4-pentyliodobenzene (6.0g, 21.9 mmol), bromopentafluorobenzene (5.4g, 21.9 mmol) and copper powder (6g) was heated in a stainless steel

reaction bomb at 200°C for 15 hours. Using a procedure identical to that described for the preparation of **(1a)**, 4-pentyl-2',3',4',5',6'-pentafluorobiphenyl was obtained as a white crystalline solid (4.9g, 72%) mp: 53–54°C. ^{1}H NMR δ7.35, m, 2H, Ar-H3' Ar-H5'; 7.31, m, 2H, Ar-H2' Ar-H6'; 2.68, t, 2H, Ar-CH_2; 1.79, m, 2H, Ar-CH_2-CH_2; 1.45–132, m, 4H, Ar-$(CH_2)_2$-CH_2-CH_2; 0.95, t, 3H, Ar-$(CH_2)_4$-CH_3. IR (KBr disc) 2962(w), 2929(m), 2850(w), 1568(w), 1528(m), 1513(m), 1493(s), 1433(w), 1410(m), 1065(m), 983(s), 954(m), 818(m). Mass Spectrum: *m/z* 315(M+1, 5%), 314(M^+, 28), 258(40), 257(100), 244(5), 237(25), 188(8), 57(11), 41(21), 39(13). Anal. calcd. for $C_{17}H_{15}F_5$: C, 67.96%; H, 4.81%. Found: C, 64.9%; H, 4.8%.

4'-Hydrazino-4-pentyl-2',3',5',6'-tetrafluorobiphenyl (2b). A solution of 4-pentyl-2',3',4',5',6'-pentafluorobiphenyl **(1b)** (3.0g, 9.5 mmol) and hydrazine hydrate (6 ml) in absolute ethanol (10 ml) was heated under reflux for 16 hours. Using a procedure identical to that described for the preparation of **(2a)**, 4'-hydrazino-4-pentyl-2',3',5',6'-tetrafluorobiphenyl was obtained as a pale yellow crystalline solid (2.9g, 95%) which was used without further purification for the preparation of 4-pentyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl. ^{1}H NMR δ7.34, m, 2H, Ar-H3 Ar-H5; 7.28, m, 2H, Ar-H2 Ar-H6; 5.33, 1H, -NH-; 4.03, 2H, $-NH_2$; 2.67, t, 2H, Ar-CH_2; 1.67, m, 2H, Ar-CH_2-CH_2; 1.42–1.30, m, 4H, Ar-$(CH_2)2$-CH_2-CH_2; 0.95, t, 3H, Ar-$(CH_2)_4$-CH_3. IR (KBr disc) 3355(w), 3232(broad, w), 2956(m), 2945(m), 2853(w), 1660(w), 1513(m), 1493(s), 1471(s), 1408(w), 1308(m), 1141(m), 989(m), 953(m), 939(s), 844(m), 773(m). Mass Spectrum: *m/z* 227(m+1, 19%), 326(M^+, 92), 311(11), 310(19), 296(17), 270(18), 269(100), 254(47), 253(85), 240(25), 239(41), 238(20), 237(15), 226(21), 219(29), 206(17), 57(14), 43(40), 41(25), 39(23).

4'-Cyano-4-pentyl-2',3',5',6'-tetrafluorobiphenyl (4b). 4-Pentyl-4'-hydrazino-2',3',5',6'-pentafluorobiphenyl **(2b)** (2.9g, 9.0 mmol) was dissolved in glacial acetic acid (20 ml) and a solution of bromine in glacial acetic acid (30% w/w), was added slowly until the colour of bromine persisted and a further aliquot (20% of the volume) was added. Using a procedure identical to that described for the preparation of **(4a)**, the crude bromide was isolated and dissolved in freshly distilled *N*-methylpyrrolidone (25 ml) and treated with copper(I) cyanide (1.0g, 1.3 eqiv.) at reflux temperature for 2 hours. The crude nitrile **(4b)** was isolated and purified using a procedure identical to that described for the preparation of **(4a)**, to give 4'-cyano-4-pentyl-2',3',5',6'-tetrafluorobiphenyl as a colourless liquid which solidified at 7–9°C (1.88g, 65% with respect to **(2b)**). ^{1}H NMR δ7.40, m, 2H, Ar-H3 Ar-H5; 7.36, m, 2H, Ar-H2 Ar-H6; 2.71, t, 2H, Ar-CH_2; 1.68, m, 2H, Ar-CH_2-CH_2; 1.45–1.30, m, 4H, Ar-$(CH_2)_2$-CH_2-CH_2; 0.94, t, 3H, Ar-$(CH_2)_4$-CH_3. IR (liquid film) 2959(w), 2932(m), 2860(w), 2246(w, -C≡N), 1648(w), 1611(w), 1565(w), 1489(s), 1411(m), 1319(m), 1182(w), 987(s), 850(w). Mass Spectrum: *m/z* 322(M+1, 6%), 321(M^+, 29), 266(11), 265(71), 264(100), 245(10), 244(40), 57(20), 41(21), 39(17). High-resolution mass spectrum calculated for $C_{18}H_{15}F_4N$: 321.1140, found: 321.1139. Anal. cald. for $C_{18}H_{15}F_4N$: C, 67.28%; H, 4.70%; N, 4.36%. Found: C, 67.0%; H, 4.6%; N, 4.4%.

4-Pentyl-2',3',5',6'-tetrafluorobiphenyl **(5b)** was isolated as an additional product as a white solid (0.85g, 32% with respect to **(2b)**) mp: 30–31°C. ^{1}H NMR δ7.38, m, 2H, Ar-H3 Ar-H5; 7.32, m, 2H, Ar-H2 Ar-H6; 7.05, m, Ar-H4'; 2.69, t, 2H, Ar-CH_2; 1.68, m, 2H, Ar-CH_2-CH_2; 1.45–1.30, m, 4H,

Ar-$(CH_2)_2$-CH_2-CH_2; 0.94, t, 3H, Ar-$(CH_2)_3$-CH_3. IR (KBr disc) 3087(w), 2955(m), 2929(m), 2859(w), 1613(w), 1492(s), 1453(m), 1410(m), 1393(w), 1172(m), 1151(m), 951(m), 932(s), 880(w), 841(m), 811(w), 711(m). Mass Spectrum: *m/z* 297(M+1, 5%), 296(M^+, 22), 240(37), 239(100), 220(8), 219(35), 43(23), 39(14). High-resolution mass spectrum calculated for $C_{17}H_{16}F_4$: 296.1187, found: 296.1189.

4-Hexyl-2',3',4',5',6'-pentfluorobiphenyl (1c). A mixture of 4-hexyliodobenzene (2.0g, 6.9 mmol), bromopentafluorobenzene (1.72g, 6.9 mmol) and copper powder (2g) was heated in a stainless steel reaction bomb at 200°C for 15 hours. Using a procedure identical to that described for the preparation of **(1a)**, 4-hexyl-2',3',4',5',6'-pentafluorobiphenyl was obtained as a white crystalline solid (1.54g, 68%) mp: 51-53°C. ^{1}H NMR δ7.35, m, 2H, Ar-H3 Ar-H5; 7.31, m, 2H, Ar-H2 Ar-H6; 2.68, t, 2H, Ar-CH_2; 1.68, m, 2H, Ar-CH_2-CH_2; 1.45-1.32, m, 6H, Ar-$(CH_2)_2$-CH_2-CH_2-CH_2; 0.91, t, 3H, Ar-$(CH_2)_4$-CH_3. IR (KBr disk) 2956(w), 2929(w), 2858(w), 1513(m), 1492(s), 1410(w), 1065(m), 983(s), 862(w), 831(w). Mass Spectrum: *m/z* 329(M+1, 5%), 328(M^+, 67), 258(52), 257(100), 237(14), 71(5), 55(5), 43(29), 41(12), 39(6).

4-Hexyl-4'-hydrazino-2',3',5',6'-tetrafluorobiphenyl (2c). A solution of 4-hexyl-2',3',4',5',6'-pentafluorobiphenyl **(1c)** (0.6g, 1.8 mmol) and hydrazine hydrate (1.5 ml) in absolute ethanol (10 ml) was heated under reflux for 16 hours. Using a procedure identical to that described for the preparation of **(2a)**, 4'-hydrazino-4-hexyl-2',3',5',6'-tetrafluorobiphenyl was obtained as a pale yellow crystalline solid (0.59g, 95%) which was used without further purification for the preparation of 4-hexyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl. ^{1}H NMR δ7.35, m, 2H, Ar-H3 Ar-H5; 7.29, m, 2H, Ar-H2 Ar-H6; 5.22, 1H, -NH-; 4.01, 2H, $-NH_2$; 2.67, t, 2H, Ar-CH_2; 1.67, m, 2H, Ar-CH_2-CH_2; 1.42-1.30, m, 6H, Ar-$(CH_2)2$-CH_2-CH_2-CH_2; 0.91, t, 3H, Ar-$(CH_2)_5$-CH_3.

4'-Cyano-4-hexyl-2',3',5',6'-tetrafluorobiphenyl (4c). 4-Hexyl-4'-hydrazino-2',3',5',6'-pentafluorobiphenyl **(2c)** (0.6g, 1.7 mmol) was dissolved in glacial acetic acid (10 ml) and a solution of bromine in glacial acetic acid (30% w/w), was added slowly until the colour of bromine persisted and a further aliquot (20% of the volume) was added. Using a procedure identical to that described for the preparation of **(4a)**, the crude bromide was isolated and dissolved in freshly distilled *N*-methylpyrrolidone (25 ml) and treated with copper(I) cyanide (0.2g, 1.3 eqiv.) at reflux temperature for 2 hours. The crude nitrile **(4b)** was isolated and purified using a procedure identical to that described for the preparation of **(4a)**, to give 4'-cyano-4-hexyl-2',3',5',6'-tetrafluorobiphenyl as a colourless liquid which solidified at 21-21°C (0.32g, 56% with respect to **(2c)**). ^{1}H NMR δ7.39, m, 2H, Ar-H3 Ar-H5; 7.35, m, 2H, Ar-H2 Ar-H6; 2.70, t, 2H, Ar-CH_2; 1.68, m, 2H, Ar-CH_2-CH_2; 1.45-1.30, m, 6H, Ar-$(CH_2)_2$-CH_2-CH_2-CH_2; 0.93, t, 3H, Ar-$(CH_2)_5$-CH_3. IR (liquid film) 2960(w), 2934(s), 2861(m), 2247(m, -C≡N), 1649(m), 1612(w), 1566(w), 1489(s), 1412(s), 1320(m), 1183(m), 988(s), 847(m), 839(m). Mass spectrum: *m/z* 336(M+1, 13%), 335(M^+, 53), 266(16), 265(100), 244(20), 43(55), 41(17). High-resolution mass spectrum calculated for $C_{19}H_{19}F_4N$: 335.1297, found 335.1302.

4-Hexyl-2',3',5',6'-tetrafluorobiphenyl **(5c)** was isolated as an additional product as a white solid (0.85g, 32% with respect to **(2c)**) mp: 41-42°C. ^{1}H NMR δ7.38, m, 2H, Ar-H3 Ar-H5; 7.31, m, 2H,

Ar–H2 Ar–H6; 7.05, m, Ar–H4'; 2.69, t, 2H, Ar–CH_2; 1.69, m, 2H, Ar–CH_2–CH_2; 1.45–1.28, m, 6H, Ar–$(CH_2)_2$–CH_2–CH_2–CH_2; 0.91, t, 3H, Ar–$(CH_2)_5$–CH_3. IR (KBr disk) 2954(w), 2932(w), 1612(w), 1492(s), 1454(w), 1410(w), 1288(w), 1172(m), 1151(w), 931(m), 824(m), 712(w). Mass spectrum: *m/z* 311(M+1, 13%), 310(M^+, 60), 240(49), 239(100), 219(13), 43(17). High-resolution mass spectrum calculated for $C_{19}H_{20}F_4$: 310.1344, Found: 310.1352.

4-Heptyl-2',3',4',5',6'-pentafluorobiphenyl (1d). A mixture of 4-heptyliodobenzene (6.0g, 19.8 mmol), bromopentafluorobenzene (4.9g, 19.8 mmol) and copper powder (6g) was heated in a stainless steel reaction bomb at 200°C for 15 hours. Using a procedure identical to that described for the preparation of **(1a)**, 4-heptyl-2',3',4',5',6'-pentafluorobiphenyl was obtained as a white crystalline solid (5.0g, 74%) mp: 44–46°C. ^{1}H NMR δ7.35, m, 2H, Ar–H3 Ar–H5; 7.31, m, 2H, Ar–H2 Ar–H6; 2.68, t, 2H, Ar–CH_2; 1.67, m, 2H, Ar–CH_2–CH_2; 1.45–1.27, m, 8H, Ar–$(CH_2)_2$–CH_2–CH_2–CH_2–CH_2; 0.90, t, 3H, Ar–$(CH_2)_6$–CH_3. IR (KBr disc) 2959(w), 2928(m), 2852(w), 1529(m), 1513(m), 1492(s), 1409(m), 1066(m), 983(s), 862(m), 843(m), 816(m). Mass spectrum: *m/z* 343(M+1, 27%), 342(M^+, 78), 283(10), 270(19), 259(15), 258(78), 257(100), 244(10), 237(21), 188(7), 115(5), 85(6), 77(5), 57(10), 55(8), 43(81), 41(30), 39(11).

4-Heptyl-4'-hydrazino-2',3',5',6'-tetrafluorobiphenyl (2d). A solution of 4-heptyl-2',3',4',5',6'-pentafluorobiphenyl **(1d)** (3.8g, 11.0 mmol) and hydrazine hydrate (8.0 ml) in absolute ethanol (10 ml) was heated under reflux for 16 hours. Using a procedure identical to that described for the preparation of **(2a)**, 4'-hydrazino-4-heptyl-2',3',5',6'-tetrafluorobiphenyl was obtained as a pale yellow crystalline solid (3.63g, 93%) which was used without further purification for the preparation of 4-heptyl-4'-cyano-2',3',5',6'-tetrafluorobiphenyl. ^{1}H NMR δ7.35, m, 2H, Ar–H3 Ar–H5; 7.28, m, 2H, Ar–H2 Ar–H6; 5.33, 1H, –NH–; 4.03, 2H, $-NH_2$; 2.66, t, 2H, Ar–CH_2; 1.66, m, 2H, Ar–CH_2–CH_2; 1.42–1.25, m, 8H, Ar–$(CH_2)2$–CH_2–CH_2–CH_2–CH_2; 0.90, t, 3H, Ar–$(CH_2)_5$–CH_3. Mass spectrum: *m/z* 355(M+1, 2), 354(M^+, 6), 339(6), 254(20), 240(4), 239(8), 169(6), 91(28), 77(8), 55(12), 43(100), 41(42), 39(16). IR (KBr disc) 3356(w), 3232(broad, w), 2956(m), 2922(s), 2852(w), 1659(w), 1512(m), 1493(s), 1470(s), 1408(w), 1308(w), 1141(m), 988(m), 953(m), 940(m), 838(m).

4'-Cyano-4-heptyl-2',3',5',6'-tetrafluorobiphenyl (4d). 4-Heptyl-4'-hydrazino-2',3',5',6'-pentafluorobiphenyl **(2d)** (3.6g, 10.1 mmol) was dissolved in glacial acetic acid (30 ml) and a solution of bromine in glacial acetic acid (30% w/w), was added slowly until the colour of bromine persisted and a further aliquot (20% of the volume) was added. Using a procedure identical to that described for the preparation of **(4a)**, the crude bromide was isolated and dissolved in freshly distilled *N*-methylpyrrolidone (25 ml) and treated with copper(I) cyanide (1.18g, 1.3 eqiv.) at reflux temperature for 2 hours. The crude nitrile **(4b)** was isolated and purified using a procedure identical to that described for the preparation of **(4a)**, to give 4'-cyano-4-heptyl-2',3',5',6'-tetrafluorobiphenyl as a colourless liquid which solidified at 26–28°C (1.9g, 56% with respect to **(2d)**). ^{1}H NMR δ7.41, m, 2H, Ar–H3 Ar–H5; 7.37, m, 2H, Ar–H2 Ar–H6; 2.72, t, 2H, Ar–CH_2; 1.70, m, 2H, Ar–CH_2–CH_2; 1.45–1.25, m, 8H, Ar–$(CH_2)_2$–CH_2–CH_2–CH_2–CH_2; 0.92, t, 3H, Ar–$(CH_2)_5$–CH_3. Mass spectrum: *m/z* 350(M+1, 14%), 349(M^+, 66), 266(16), 265(100), 264(91), 244(16), 85(7), 57(11), 43(94), 41(26), 39(11). IR (KBr disc) 2958(m), 2931(s), 2858(m), 2246(w, –C≡N), 1648(m),

1489(s), 1411(s), 1320(m), 1182(w), 987(s), 849(w), 841(w). High-resolution mass spectrum calculated for $C_{28}H_{19}F_4N$: 349.1453, found: 349.1438. Anal. calcd. for $C_{20}H_{19}F_4N$: C, 68.75%; H, 5.48%. Found C, 69.0%; H, 5.6%.

4-Heptyl-2',3',5',6'-tetrafluorobiphenyl **(5d)** was isolated as an additional product as a white solid (1.21g, 37% with respect to **(2d)**) mp: 30-31°C. ^{1}H NMR δ7.39, m, 2H, Ar-H3 Ar-H5; 7.32, m, 2H, Ar-H2 Ar-H6; 7.05, m, Ar-H4'; 2.68, t, 2H, Ar-CH_2; 1.68, m, 2H, Ar-CH_2-CH_2; 1.45-1.28, m, 8H, Ar-$(CH_2)_2$-CH_2-CH_2-CH_2-CH_2; 0.91, t, 3H, Ar-$(CH_2)_6$-CH_3. IR (KBr disc): 3085(w), 2956(w), 2928(m), 2855(w), 1610(w), 1492(s), 1454(m), 1410(w), 1393(w), 1288(w), 1172(m), 1151(m), 953(m), 932(m), 841(m), 711(w). Mass spectrum: *m/z* 325(M+1, 14), 324(M^+, 59), 252(10), 240(60), 219(100), 91(9), 57(14), 43(48), 41(20). High-resolution mass spectrum calculated for $C_{19}H_{20}F_4$: 324.1501, found 324.1520.

References.

¶ The correct systematic numbering of the substituted biphenyl skeleton, according to IUPAC rules for nomenclature depends on the priority of the substituents. However, *in this paper* for clarity and consistency throughout the series of compounds, the substituents on the fluorinated ring have *always* been numbered with primes.

1. For Part I see the preceding paper in this issue.
2. Yamazaki, Y. Japan Kokai Tokyo Koho 79/05886 (CL C09K3/34)
3. Vani, G.V. *Mol. Cryst. Liq. Cryst*, **1983**, *99*, 21-7.
4. Field, L.D., Hambley, T.W. and Pierens, G.K. submitted for publication in *Acta Cryst*. **1990**.
5. Field, L.D., Skelton, B.W., Sternhell, S. and White, A.H. *Aust. J. Chem.*, **1985**, *38*, 391-9.
6. Goodhand, N. and Harmor, T.A. *Acta Cryst.*, **1978**, *B34*, 1644-7.
7. Brock, C.P., Naae, D.G., Goodhand, N. and Harmor, T.A. *Acta Cryst.*, **1984**, *B40*, 3691-6.
8. Vogel, A.I. *Textbook of Practical Organic Chemistry*, 4th Ed, Longmans, 1978, p288.