298. *The Mesomorphic Transition Temperatures of 3'-Substituted 4'-n-Octyloxydiphenyl-4-carboxylic Acids.*

By G. W. GRAY and B. M. WORRALL.

The preparation of 3'-fluoro- and -iodo-4'-*n*-octyloxydiphenyl-4-carboxylic acids now makes it possible to compare the relative effects of 3'-H-, -F-, -Cl-, -Br-, -I-, and -NO$_2$-substituents upon the mesomorphic transition temperatures. The nematic–isotropic transition temperatures decrease quite regularly with increasing molecular breadth, but such a relationship does not hold for the smectic–nematic transition temperatures. These temperatures appear to be sensitive to change in the permanent polarisation of the molecule, and this, together with the change in molecular breadth, must be taken into account in assessing smectic–nematic transition temperatures.

THE 4'-*n*-alkoxydiphenyl-4-carboxylic acids [1] are suitable parent compounds for a study of the relative effects of substituents on the thermal stabilities of mesophases. They exhibit enantiotropic mesophases with high transition temperatures which are well separated from the melting points (solid–mesophase transition), and therefore the introduction of even bulky substituents does not eliminate the mesomorphic properties (cf. 4-*n*-alkoxy-3-bromobenzoic acids [2] which are not mesomorphic). The 3'-chloro-, -bromo-, and -nitro-derivatives [3] of these diphenyl acids have already been studied, but to establish the relative effects of the substituents F, Cl, Br, I, and NO$_2$ upon the mesomorphic properties of one particular molecule type, the 3'-fluoro- and -iodo-4'-*n*-octyloxydiphenyl-4-carboxylic acids have now been prepared. Synthetical difficulties prevented our studying a homologous series of ethers, as was possible for the chloro-, bromo-, and nitro-compounds. However, existing data show that comparisons of the transition temperatures for one particular ether or of the average transition temperatures for several ethers do not lead to substantially different results. The smectic–nematic and nematic–isotropic transition temperatures for the octyl ethers in Table 1 are therefore a reliable guide to the relative influences of the substituents on the smectic and nematic thermal stabilities.

TABLE 1. 3'-X-4'-n-*Octyloxydiphenyl-4-carboxylic acids.*

X	H	F	Cl	Br	I	NO$_2$
Smectic–nematic transition temp.	255°	254·5°	225°	214°	192·5°	214° *
Decrease in transition temp. from unsubstituted acid		0·5	30	41	62·5	41
Nematic–isotropic transition temp.	264·5	255·5	233	224	214	214 *
Decrease in transition temp. from unsubstituted acid		9	31·5	40·5	50·5	50·5

* Smectic–isotropic transition temperature.

The octyl ether of the 3'-nitro-derivative exhibits no nematic mesophase, and the smectic–isotropic transition temperature, 214°, has been used in both sets of figures in the Table. This transition temperature may be compared with the other smectic–nematic transition temperatures, and the order of increasing effect of the substituents on the thermal stability of the smectic mesophase for 4'-*n*-octyloxydiphenyl-4-carboxylic acid is H < F < Cl < Br = NO$_2$ < I. At first sight, the smectic–isotropic transition temperature for X = NO$_2$ should not be comparable with the nematic–isotropic transition temperatures for the other derivatives. However, when nematic properties cease to appear at a particular member in a homologous series, the smectic–nematic and nematic–isotropic transition temperature curves coincide, *i.e.*, the smectic–isotropic curve is a

[1] Gray, Hartley, and Jones, *J.*, 1955, 1412.
[2] Gray and Jones, *J.*, 1954, 2556.
[3] Gray, Jones, and Marson, *J.*, 1957, 393.

continuation of the nematic–isotropic curve. Regarded in this way, smectic–isotropic and nematic–isotropic transition temperatures may be compared, and the order of increasing effect of the substituents upon the nematic thermal stability of 4'-*n*-octyloxy-diphenyl-4-carboxylic acid is $H < F < Cl < Br < I = NO_2$. In support of this sequence, the order obtained for X = H, Cl, Br, and NO_2 by comparing average *nematic*–isotropic transition temperatures (*e.g.*, for the propyl–hexyl ethers) is $H < Cl < Br < NO_2$.

The nitro-group has a smaller effect upon the thermal stability of the smectic mesophase than on that of the nematic mesophase, probably [3] owing to the large $C–NO_2$ dipole moment which counteracts the separation of the molecular axes arising from the bulk of the nitro-group. In an attempt to assess the effect of substituent size upon the two mesophase types, the minimum overall molecular breadths (defined as the diameter of the smallest cylinder through which the dimerised aromatic carboxylic acid would pass, the flexible alkyl chain being assumed not to interfere) of the 3'-substituted diphenyl acid dimers have been calculated. These breadths (*R*) are plotted against the nematic and


FIG. 1*a*.

FIG. 1*b*.
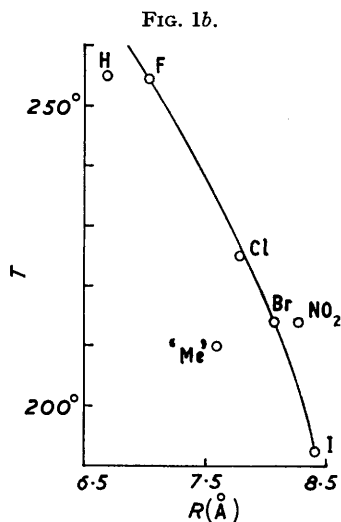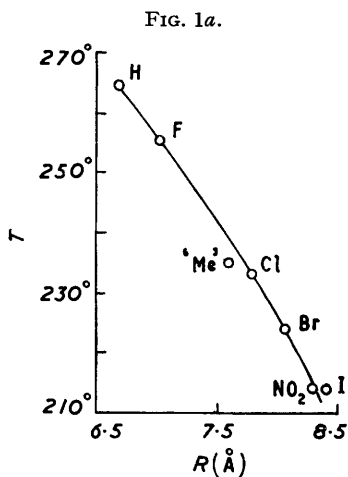
smectic transition temperatures (*T*) in Figs. 1*a* and 1*b*. For the nematic transitions (Fig. 1*a*), the transition temperatures decrease reasonably smoothly with increasing molecular breadth, and it appears that the order $H < F < Cl < Br < I = NO_2$ is determined largely by the separation of the molecular axes. Unfortunately, the pure 3'-methyl acid is not available, but in seven cases in which analogous mesomorphic methyl- and chloro-substituted compounds have been examined, the average increase in nematic–isotropic transition temperature from chloro- to methyl derivative is about 2°. This leads to a predicted nematic–isotropic transition temperature of 235° for 3'-methyl-4'-*n*-octyloxy-diphenyl-4-carboxylic acid. Using a breadth (*R*) of 7·6 Å for this molecule, we obtain a point close to the curve in Fig. 1*a*. It is particularly significant that the point for X = NO_2 lies so close to the curve, *i.e.*, the large $C–NO_2$ dipole moment appears to have little influence upon the thermal stability of the nematic mesophase. Thus, molecular interactions of the dipole–dipole or induced dipole type do not appear to contribute significantly to the intermolecular attractions in the nematic mesophase. Dispersion forces, arising from molecular polarisability, must therefore account for the molecular interactions which maintain the parallel orientation of the molecules in the nematic state. The gas-phase relation being assumed to hold, the energy of interaction for these forces is proportional to (molecular polarisability)^2/(molecular separation).[6] As the separation of the molecular axes increases, the interaction energy will fall off rapidly (cf. the increasing gradient of the curve in Fig 1*a* with increasing *R*). The molecular polarisabilities will

interfere with a smooth-curve relationship between T and R only if the polarisabilities change in an irregular way with increasing substituent size.   In fact, Fig. 2 shows that the C–X bond refractions increase fairly regularly with increasing R.   Therefore the increases in polarisability with change in substituent X will merely reduce the gradient of the curve in Fig. 1*a*.

Fig. 1*b* shows that the relation between the smectic–nematic transition temperatures and the molecular breadths is not simple.   Thus, X = F has a small effect upon the thermal stability of the mesophase, and the breadth increase must be counteracted by the increase in intermolecular interaction arising from the increase in permanent polarisation on passing from X = H to X = F.   The points for X = F, Cl, Br, and I lie on a curve, presumably because no large fluctuation in dipole moment occurs along this sequence. However, with X = NO_2, the point is displaced from this curve by some 13°, and the higher thermal stability may be explained by the large C–NO_2 dipole moment.   Data on

FIG. 2.
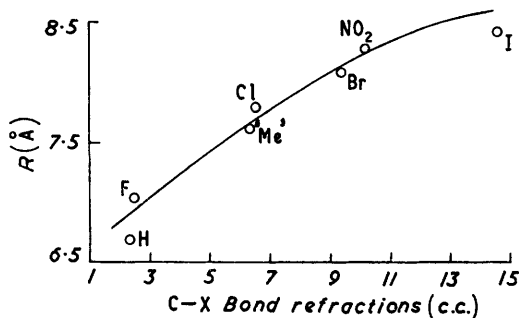
the smectic thermal stabilities of methyl compounds are limited, but from other analogous methyl and chloro-compounds, an approximate smectic–nematic transition temperature of 210° would be predicted for 3'-methyl-4'-*n*-octyloxydiphenyl-4-carboxylic acid.   This point would lie below the above curve by some 23°, explained in this case by the small C–CH_3 dipole moment.

It appears that in the smectic mesophase, the intermolecular attractions arising from dispersion forces are supplemented by dipolar attractions, *i.e.*, by dipole–dipole and induced dipole interactions.   That is, the thermal stability of a mesophase will be reduced by substitution which leads to an increase in molecular breadth, but this effect will be counteracted for both mesophase types by the increased polarisability of the substituted molecules, and in the case of the smectic mesophase only, by the substituent's dipole moment.   These facts are understandable in terms of the generally accepted molecular orientations in the mesophases.   Thus, in the smectic mesophase the molecules are arranged parallel to one another, in layers, since this arrangement gives rise to a strong attraction between the dipoles which operate across the long axes of smectogenic molecules. At the smectic–nematic transition, thermal effects increase the intermolecular separation and weaken these dipolar attractions sufficiently for the molecules to slide out of the layers in the direction of their long axes, whilst retaining the overall parallel orientation. Thus, in the nematic mesophase the ends of the molecules are arranged randomly, so it is less probable that dipoles acting across the molecular axes will lie sufficiently close to give rise to any attraction.   Moreover, if, as is often the case, there are two such dipoles acting in opposite directions at opposite ends of the molecule, it is likely that the dipoles in neighbouring molecules will lead to repulsion as often as to attraction, so resulting in a low, overall, average dipole interaction.   Such considerations would explain the apparent unimportance of permanent dipoles in relation to the nematic mesophase.

These results cannot be confirmed by reference to other series of substituted meso-morphic compounds.   Thus, the 4-*n*-alkoxy-3-bromo-, -iodo- and -nitro-benzoic acids

and the *trans*-4-*n*-alkoxy-3-iodo- and -nitro-cinnamic acids are not mesomorphic, and in the 5-substituted 6-*n*-alkoxy-2-naphthoic acids [4] the behaviour is anomalous because of the protection of the 5-substituent by the 8-H atom. It would however seem worth while to study the effect of introducing substituents of diverse size and polarity into given systems in order to verify these ideas, since attempts to realise quantitative relationships between mesomorphic and molecular properties would be assisted by this knowledge of the particular types of molecular interaction operating in given mesophase types.

Finally, the purely smectic propyl 3'-fluoro-4'-*n*-octyloxydiphenyl-4-carboxylate has been made, and has a smectic–isotropic transition temperature of 59·5°. The analogous chloro-compound is not mesomorphic, but the 3'-nitro-ester has a smectic–isotropic transition at 47°. Here again, the large C–NO$_2$ dipole moment is giving rise to a higher transition temperature than would be expected.

It is interesting to record the variations in the decreases in smectic mesophase thermal stability, ΔT(H–X), for a given substituent in different systems. ΔT(H–F) for propyl 3'-substituted-4'-alkoxydiphenyl-4-carboxylates is 43·5°, for 3-substituted-4-alkoxy-benzoic acids 10°, and for 3'-substituted-4'-alkoxydiphenyl-4-carboxylic acids 0·5°. Such variations are expected, since on passing from X = H to X = F the increase in inter-molecular attraction due to the larger C–F dipole and the greater polarisability of the substituted molecule will depend on the total polarisability of the individual molecules. Indeed, the greater the molecular polarisability, the larger will be the increase in inter-molecular attraction due to both induced dipole attraction and dispersion forces, and the smaller will be the overall effect of a substituent in decreasing the smectic thermal stability. This is borne out by the above figures, the three compound types being arranged in order of increasing molecular polarisability (the acids are dimeric). Since dipoles are less important in the nematic mesophase, these arguments will apply then only to the dispersion forces, and there should be less fluctuation in the ΔT(H–X) figures for nematic–isotropic transitions for a given substituent: ΔT(H–F) for 3-substituted-4-alkoxybenzoic acids is 25·5°, and for 3'-substituted-4'-alkoxydiphenyl-4-carboxylic acids is 9°.

EXPERIMENTAL

M. p.s are corrected for exposed stem. Light petroleum had b. p. 40—60°.

Determination of Transition Temperatures.—The m. p.s and mesomorphic transition temperatures were determined in the usual way with an electrically heated microscope block [5] in conjunction with a projection system.[6]

Materials.—Attempts to iodinate the 4'-alkoxydiphenyl-4-carboxylic acids had limited success, since with increasing length of the alkyl chain the amount of un-iodinated material increased, and only in the case of the methyl ether was a reasonable yield of the pure iodo-derivative obtained. Moreover, the methyl ether could not be demethylated without loss of iodine, and 4'-hydroxydiphenyl-4-carboxylic acid could not be restricted to mono-iodination. Several of the longer-chain 4'-alkoxy-3'-nitrodiphenyl-4-carboxylic acids [3] were catalytically reduced to the amines and attempts to replace the amino-group by iodine were made. Although the products were repeatedly crystallised and chromatography on alumina was used, pure compounds could not be isolated. It was therefore decided to prepare 3'-iodo-4'-*n*-octyloxy-diphenyl-4-carboxylic acid *via* its ester by carrying out an *N*-nitrosoacetylation between 3-iodo-4-*n*-octyloxyacetanilide and methyl benzoate. This method was successful and was also applied to the preparation of the analogous 3'-fluoro-derivative.

3'-Iodo-4'-methoxydiphenyl-4-carboxylic Acid.—The parent acid (1 mol.) was dissolved in ethanol–concentrated sulphuric acid (4 : 1; v/v) at 40—50°. Iodine (3 mol.) and yellow mercuric oxide (3 mol.) were added and the mixture stirred for 10 hr. at 40—50°. Inorganic matter was filtered off, and the product obtained on dilution of the filtrate was hydrolysed by refluxing it for 90 min. with 2N-ethanolic potassium hydroxide. The hydrolysate was diluted and acidified, and the product was filtered off and crystallised three times from glacial acetic

[4] Gray and Jones, *J.*, 1955, 236.
[5] Gray, *Nature*, 1953, **172**, 1137.
[6] Gray and Ibbotson, *Nature*, 1955, **176**, 1160.

acid and once from ethanol to give the colourless *3′-iodo-4′-methoxydiphenyl-4-carboxylic acid*, m. p. 271·5° (73%) (Found: C, 47·7; H, 3·6; I, 35·6. $C_{14}H_{11}O_3I$ requires C, 47·4; H, 3·2; I, 35·8%).

1-Iodo-2-n-octyloxybenzene.—*o*-Iodophenol (110 g., 0·5 mole) in absolute ethyl alcohol (300 ml.) containing sodium (11·5 g., 0·5 g.-atom) and *n*-octyl iodide (132 g., 0·505 mole), was refluxed for 12 hr. About one half of the alcohol was distilled off, and the residue poured into water (500 ml.). The carbon tetrachloride extract of the oily ether was washed thoroughly with aqueous sodium hydroxide, then with water, and dried. Removal of solvent under reduced pressure gave 119·5 g. (72%) of 1-*iodo*-2-n-*octyloxybenzene*, b. p. 143—145°/1 mm. (Found: I, 38·0. $C_{14}H_{21}OI$ requires I, 38·2%).

2-Iodo-4-nitro-1-n-octyloxybenzene.—(a) *By nitration.* 2-Iodo-1-*n*-octyloxybenzene (33·2 g., 0·1 mole) was added dropwise during 25 min. to a stirred mixture of glacial acetic acid (125 ml.) and fuming nitric acid (125 ml., *d* 1·5) maintained at 0° ± 1°. A pale yellow solid began to separate 5 min. after commencing the addition. When all the iodo-compound had been added, the mixture was stirred for 5 min. and poured into water (500 ml.). The pale yellow solid was filtered off, washed with 2N-sodium hydroxide and with water, and dried in a vacuum desiccator. Crystallisation from light petroleum gave pale yellow prisms, 27 g. (71·5%), m. p. 48—50·5°. Two further crystallisations from the same solvent gave pure 2-*iodo*-4-*nitro*-1-n-*octyloxybenzene*, m. p. 50·5—51° (Found: C, 44·9; H, 5·7; N, 3·4; I, 34·1. $C_{14}H_{20}O_3NI$ requires C, 44·6; H, 5·3; N, 3·7; I, 33·7%).

(b) *By alkylation.* 2-Iodo-4-nitrophenol[7] was octylated by the general procedure for alkylating *p*-hydroxybenzaldehyde.[8] The solid residue after removal of the *cyclo*hexanone yielded pure 2-iodo-4-nitro-1-*n*-octyloxybenzene (54%), m. p. and mixed m. p. with specimen from nitration 50—51°, after four crystallisations from light petroleum.

3-Iodo-4-n-octyloxyaniline.—An alcoholic solution of the nitro-compound was reduced in the usual way with stannous chloride and concentrated hydrochloric acid. The solution was reduced to half its volume by distillation and the residue neutralised carefully with 10N-sodium hydroxide at 0—10°. The amine extract with chloroform was washed with water and dried. Removal of the solvent and distillation under reduced pressure gave 3-*iodo*-4-n-*octyloxyaniline* (Found: I, 36·3. $C_{14}H_{22}ONI$ requires I, 36·6%) as a pale yellow viscous oil, b. p. 174—178°/1 mm., in 58% yield. The *acetyl derivative* was prepared by use of acetic anhydride and ice-cold 2N-sodium hydroxide. The crude product was crystallised from methanol and then from benzene–light petroleum (1 : 1·5 by volume), after which the m. p. was 122—122·5° (Found: C, 49·4; H, 6·0; N, 3·2; I, 32·2. $C_{16}H_{24}O_2NI$ requires C, 49·35; H, 6·2; N, 3·6; I, 32·6%).

o-Fluorophenol.—*o*-Fluoroanisole[2] (113 g.) was refluxed for 14 hr. in glacial acetic acid (220 ml.) and 48% hydrobromic acid (220 ml.). Solid sodium hydrogen carbonate was added to the cooled reaction mixture whereupon, before reaching neutral point, the phenol separated as an oily upper layer. The oil was stirred with solid sodium hydrogen carbonate until no more carbon dioxide was evolved, then chloroform was added, and the organic layer removed and dried (Na_2SO_4). The solvent was removed and *o*-fluorophenol, 56 g. (56%), b. p. 142—148°, obtained by distillation of the residue through a short fractionating column.

1-Fluoro-2-n-octyloxybenzene.—*o*-Fluorophenol was octylated as for *o*-iodophenol. The *octyl ether*, a pale yellow oil, b. p. 156—160°/20 mm., was obtained in 75% yield (Found: C, 74·8; H, 9·3. $C_{14}H_{21}OF$ requires C, 75; H, 9·4%).

2-Fluoro-4- and -6-nitro-1-n-octyloxybenzene.—The nitration conditions were as for the iodo-analogue. The addition time was 40 min., stirring was continued for a further 20 min., and the mixture remained homogeneous. The oily nitration product (after dilution) was extracted with ether, and the extract washed (aqueous sodium carbonate and water) and dried (Na_2SO_4). The ether was removed and the residue distilled under vacuum. The mixture (80%) of 4- and -6-*nitro-isomers* (Found: N, 5·14. Calc. for $C_{14}H_{20}O_3NF$: N, 5·4%), b. p. 140—160°/0·1 mm., was collected. Attempts to separate the isomers by crystallisation were unsuccessful and the mixture was reduced and acetylated.

3-Fluoro-4-n-octyloxyacetanilide.—The mixture of 2-fluoro-4- and -6-nitro-1-*n*-octyloxy-benzenes was reduced as for the 2-iodo-4-nitro-analogue. It was not possible to separate the isomeric amines by distillation, and these were obtained as a wax (55%), b. p. 140—150°/0·5 mm., which could not be crystallised. Acetylation of the amines with acetic anhydride and

[7] Hodgson and Moore, *J.*, 1925, 2260.
[8] Gray and Jones, *J.*, 1954, 1467.

ice-cold 2N-sodium hydroxide gave a solid, m. p. 69—74°, which crystallised readily from aqueous alcohol. Two further crystallisations from benzene–light petroleum (1 : 1 v/v) gave colourless needles of 3-*fluoro*-4-*n-octyloxyacetanilide* (53%), m. p. 83·5—84·5° (Found: C, 68·5; H, 8·6; N, 5·3. $C_{16}H_{24}O_2NF$ requires C, 68·3; H, 8·5; N, 5·0%). The isomeric acetylamine was not isolated, but the orientation of the substituents in the product was proved by the following small-scale experiments.

2-Fluoro-4-nitrophenol [9] (3 g.) was octylated (cf. above alkylation of 2-iodo-4-nitrophenol), and the crude, oily product reduced and acetylated as for the analogous iodo-derivative. The resulting 3-fluoro-4-*n*-octyloxyacetanilide was purified and had m. p. 83—84°, undepressed on admixture with the above product.

3'-*Fluoro*- *and* 3'-*Iodo*-4'-*n-octyloxydiphenyl*-4-*carboxylic Acids.*—The preparations were carried out with the pure 3-fluoro- and 3-iodo-4-octyloxyacetanilides. The purified acetylamine (20 g.) was dissolved in a mixture of glacial acetic acid (140 ml.) and acetic anhydride (60 ml.) and placed in a bolt-head flask fitted with an efficient stirrer, a thermometer, and a dropping funnel. Fused sodium acetate (anhydrous) (20 g.) was finely powdered and added to the solution, together with phosphoric oxide (2 g.). The mixture was stirred and cooled in ice, and the temperature maintained at 8° during the gradual addition of nitrosyl chloride [10] (20 g.) in glacial acetic acid (20 ml.) and acetic anhydride (10 ml.), and for 30 min. after the addition. The mixture was poured into ice and water (1000 g.) and stirred to hydrolyse the acetic anhydride. The suspension of the greenish-yellow, oily N-nitroso-derivative was extracted with methyl benzoate (500 ml.) which was then washed first with water and then with 2N-aqueous sodium hydroxide (400 ml.), and dried (Na_2SO_4) for a few minutes. The dried extract was then stirred for 60 hr. with anhydrous sodium sulphate (48 g.) and sodium carbonate (32 g.), whereupon the salts were filtered off and the methyl benzoate distilled off under vacuum. Distillation of the residues gave the following fractions: Fluoro-; 195—205°/0·1 mm. (5 g.), 205—212°/0·1 mm. (4·5 g.), 212—230°/0·1 mm. (4·5 g.); Iodo-; 190—220°/0·1 mm. (2·6 g.), 220—235°/0·1 mm. (5·6 g.), 235—242°/0·1 mm. (0·4 g.). These oily fractions, consisting of mixtures of the methyl 3'-fluoro- and 3'-iodo-4'-octyloxydiphenyl-2-, -3-, and -4-carboxylates, were hydrolysed separately by boiling for 90 min. with 80% methyl alcohol (25 ml.) containing 2·5 g. of potassium hydroxide, for each 1 g. of oil. The hydrolysates were diluted with water and acidified with concentrated hydrochloric acid to precipitate the gummy mixture of acids. Although the fractions were hydrolysed separately, crystallisation of the gums from glacial acetic acid gave separation of the 4-carboxylic acid from each fraction. This applied to both fluoro- and iodo-derivatives, and the yield of the 4-carboxylic acid increased with the b. p. of the fraction hydrolysed. The separate fractions of the 4-carboxylic acids were combined and crystallised to constant m. p. from benzene and glacial acetic acid. Both acids were obtained as colourless needles and exhibited mesomorphism (see Table 1 for transition temperatures): 3'-*iodo*-4'-*n-octyloxydiphenyl*-4-*carboxylic acid*, 2·2 g. (9·5%) (Found: C, 55·3; H, 5·2; I, 28·6. $C_{21}H_{25}O_3I$ requires C, 55·75; H, 5·5; I, 28·1%) had m. p. 180·5°, and 3'-*fluoro*-4'-*n-octyloxydiphenyl*-4-*carboxylic acid*, 2·5 g. (10·3%) (Found: C, 73·0; H, 7·3. $C_{21}H_{25}O_3F$ requires C, 73·2; H, 7·3%), had m. p. 119·5°.

Because of their mesomorphic behaviour, the orientation in these acids was obviously such that the carboxyl group was in the 4-position in the diphenyl ring, but it was decided to verify this chemically. Each acid (0·5 g.) was boiled for 1 hr. with glacial acetic acid containing excess of potassium permanganate. The mixtures were cooled and the manganese dioxide was filtered off and extracted several times by stirring with aqueous ammonium hydroxide. Acidification of the ammoniacal filtrates gave a precipitate of terephthalic acid, confirmed by conversion into dimethyl terephthalate, m. p. 140°.

n-*Propyl* 3'-*Fluoro*-4'-*n-octyloxydiphenyl*-4-*carboxylate.*—The *ester* was prepared in the usual way from the acid, propan-1-ol, and concentrated sulphuric acid, and crystallised from methyl alcohol and from light petroleum. The colourless mesomorphic product had m. p. 46° (Found: C, 74·6; H, 8·1. $C_{24}H_{31}O_3F$ requires C, 74·6; H, 8·0%).

THE UNIVERSITY, HULL.

[9] Berg and Newbery, *J.,* 1949, 642.
[10] "Organic Reactions," John Wiley and Sons, Inc., New York, Volume II, p. 251.