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# THE SYNTHESIS AND STABILITY OF SOME PERFLUOROALKYL- AND PERFLUOROALKYLENE-1,2,4- AND 1,3,4-OXADIAZOLES*

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## SUMMARY

5-Perfluoroalkyl-3-phenyl-1,2,4-oxadiazoles have been synthesised directly from benzamidoxime and perfluoromonoacyl chlorides. However, a more complex pattern of products was observed in the reaction between arylamidoximes and perfluorodiacyl chlorides. Depending on the conditions, the products were *O,O'*-perfluorodiacyl di(arylamidoximes), α, ω-bis(3-aryl-1,2,4-oxadiazol-5-yl)perfluoroalkanes and arylamidoxime (3-aryl-1,2,4-oxadiazol-5-yl)perfluorocarboxylates.

Some properties [*e.g.* ultraviolet spectra (UV), chemical and thermal stability] of perfluoroalkyl- and perfluoroalkylene-1,2,4-oxadiazoles have been studied and the results compared with those for analogous 1,3,4-oxadiazoles.

## INTRODUCTION

A major study, aimed at thermally stable elastomers, has involved determining the effect of introducing perfluoroalkylene linking units between phenylene groups[1,2,3] and heterocyclic nuclei in polymeric structures.

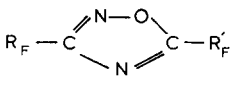
The model compound approach has frequently been employed in the synthesis of thermally stable polymers in an attempt to assess the ease and yield potential of the projected polymer-forming reaction, the occurrence of byproducts and the stability of the resulting system. In this paper there is described the synthesis of perfluoroalkyl- and perfluoroalkylene-1,2,4-oxadiazoles previously reported[4] only briefly and it is shown how the nature of the reaction between perfluorodiacyl chlorides and arylamidoximes appears to preclude its extension to polymer-forming reactions. Also demonstrated is the adverse effect of a perfluoroalkyl substituent

on the stability of the 1,2,4-oxadiazole ring and this is compared with the effect on the 1,3,4-oxadiazole ring.

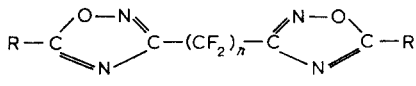
## RESULTS AND DISCUSSION

### *1,2,4-Oxadiazoles*

The preparation of a number of 3,5-bis(perfluoroalkyl)-1,2,4-oxadiazoles (I) ($R_F = R_F' = CF_3$, $C_2F_5$, $C_3F_7$, $C_7F_{15}$; $R_F = C_3F_7$, $R_F' = CF_3$) and bis-1,2,4-oxadiazolylperfluoroalkanes (II) ($n = 3, 4, 8$) ($R = CH_3$, $CF_3$, $C_3F_7$) has been reported[5,6].

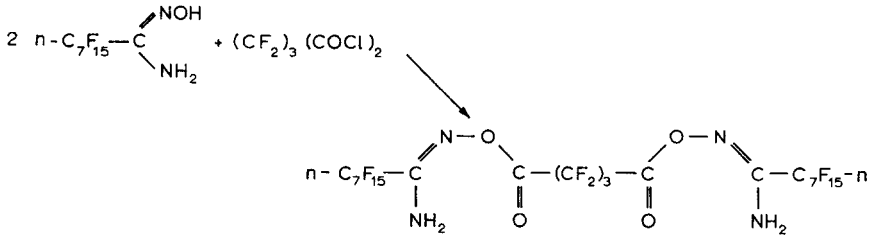


(I)



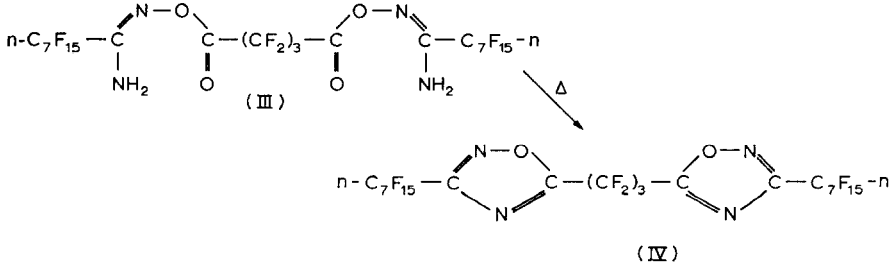
(II)

In a limited study of compounds (I) ($R_F = C_7F_{15}$, $R_F' = C_3F_7$, $C_7F_{15}$) it was not possible to reproduce the high yields obtained by Brown and Wetzel[5]. Likewise, after prolonged reaction in *N,N*-dimethylformamide (DMF)/pyridine solution, pentadecafluoro-n-octanamidoxime and hexafluoroglutaryl chloride gave only a low yield of *O,O'*-hexafluoroglutaryl di(pentadecafluoro-n-octanamidoxime) (III).



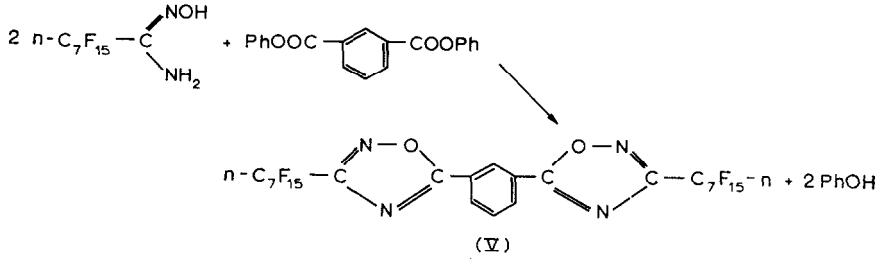
(III)

This was dehydrated to 1,3-bis(3-pentadecafluoro-n-heptyl-1,2,4-oxadiazol-5-yl)-hexafluoropropane (IV) by heating with phosphorus pentoxide at 230–250°.



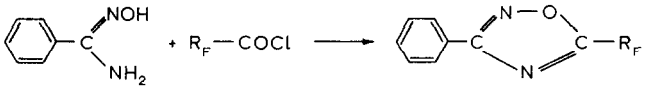
(IV)

A correspondingly low yield of 1,3-bis(3-pentadecafluoro-n-heptyl-1,2,4-oxadiazol-5-yl)benzene (V) was obtained after prolonged treatment of pentadecafluoro-n-octanamidoxime with diphenyl isophthalate in DMF at 130°.



(V)

With benzamidoxime, however, very little difficulty was encountered. Perfluoro-propionyl, -n-butyryl and -n-octanoyl chlorides gave dense white precipitates when added to a solution of benzamidoxime in ether containing an equivalent of pyridine. After leaving all three reactions for several hours at room temperature the precipitates had almost disappeared, only a small precipitate of base hydrochloride remained and the corresponding 5-perfluoroalkyl-3-phenyl-1,2,4-oxadiazoles (VI) were obtained in high yield (Table 1).



(VI)

Pentadecafluoro-n-octanoic anhydride reacted vigorously with benzamidoxime in ether solution to give (after heating for 3–4 h) a 70% yield of 5-pentadecafluoro-n-heptyl-3-phenyl-1,2,4-oxadiazole ((VI); $R_F$ = n-$C_7F_{15}$).

TABLE 1

5-PERFLUOROALKYL-3-PHENYL-1,2,4-OXADIAZOLES[a,b] (VI)

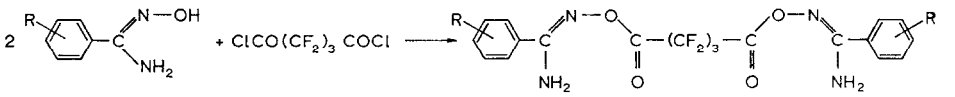
| $R_F$ | Yield (%) | M.p. (°C) or b.p. (°C/mmHg)[c] | $n_D^{22}$ | Analysis: Calcd. % | | | | Found % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | C | H | F | N | C | H | F | N |
| $C_2F_5$ (nc) | 72 | 45–46/0.1 | 1.4420 | 45.6 | 1.9 | 36.0 | 10.6 | 46.1 | 2.3 | 36.0 | 10.6 |
| n-$C_3F_7$(nc) | 71 | 48–49/0.1 | 1.4250 | 42.0 | 1.6 | 42.4 | 8.9 | 41.7 | 1.7 | 42.2 | 8.9 |
| n-$C_7F_{15}$(nc) | 80 | 42–43 | — | 35.0 | 1.0 | 55.4 | 5.4 | 35.3 | 0.7 | 55.9 | 5.3 |

[a] $\nu_{max.}$ = 1600–1525 (C=N str.), 1360–1330 ($C_2N_2O$ ring), 1250–1120 $cm^{-1}$ (C–F str.).
[b] All infrared (IR) spectra were recorded on a Perkin–Elmer Infracord Model 137 spectrometer.
[c] 1 mmHg = 133.3 N $m^{-2}$.

The reactions of three perfluorodiacyl chlorides, malonyl, succinyl and glutaryl with arylamidoximes have been studied. These diacyl chlorides behaved rather differently from perfluoromonoacyl chlorides.

(a) Hexafluoroglutaryl chloride gave three products:

(i) Reaction with the arylamidoximes (VII) (R = H, *p*-$CH_3$, *m*-$CH_3$) in ether solution containing an equivalent of pyridine gave the expected *O,O'*-hexafluoroglutaryl di(arylamidoximes) (VIII) (R = H, *p*-$CH_3$, *m*-$CH_3$) in good yield (Table 2).



(VII) (VIII)

Whilst there are two possible positions for acylation in amidoximes, it is now accepted[7] that, with few exceptions, *O*-acylation occurs. Infrared spectra confirmed that in the present compounds acylation had followed the customary course: the position of the carbonyl bands was characteristic for fluorinated esters[8] and in accord with the study by Brown and Wetzel[5] of *O*-perfluoroacyl perfluoroalkylamidoximes. Additionally, the associated OH band of the arylamidoximes had disappeared. The spectrum of *O,O'*-hexafluoroglutaryl di(benzamidoxime) (VIII) (R = H), typical for these compounds, is shown (Fig. 1).

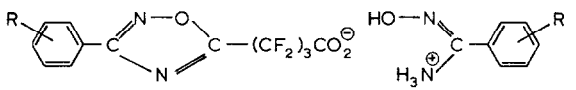
TABLE 2

*O,O'*-HEXAFLUOROGLUTARYL DI(ARYLAMIDOXIMES)[a] (VIII)

| R | Yield (%) | M.p. (°C) | Analysis: Calcd. % | | | | Found % | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | C | H | F | N | C | H | F | N |
| H (nc) | 67 | 137–138 | 48.2 | 3.1 | 23.2 | 11.8 | 47.9 | 3.0 | 23.9 | 11.8 |
| *p*-$CH_3$(nc) | 74 | 149–150 | 50.0 | 3.7 | 22.6 | 11.1 | 49.7 | 3.2 | 22.7 | 10.9 |
| *m*-$CH_3$(nc) | 58 | 143–144 | 50.0 | 3.7 | 22.6 | 11.1 | 50.2 | 3.4 | 22.4 | 11.0 |

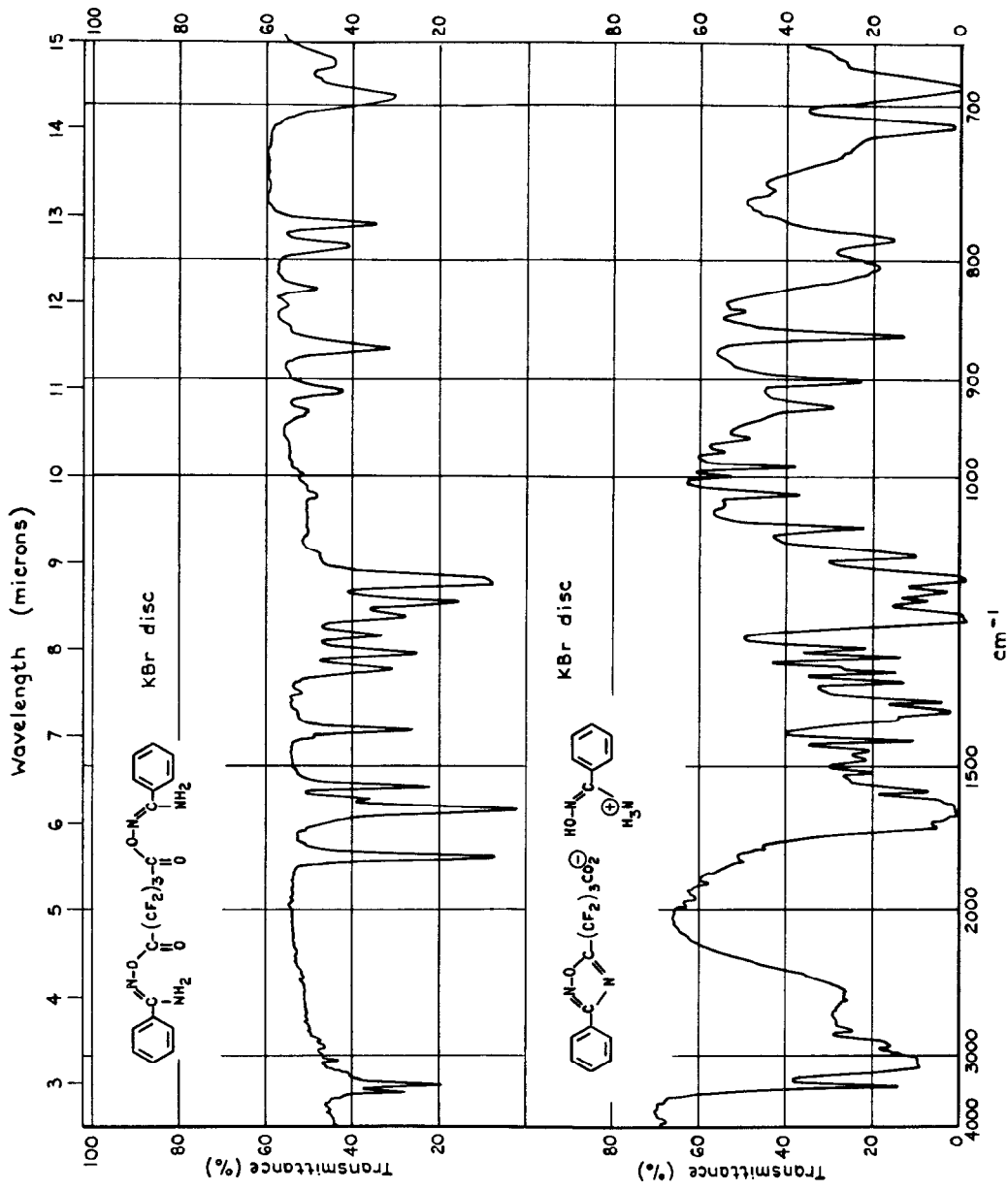
[a] $\nu_{max.}$ = 3450(m) and 3350(s) (N–H str.), 1780–1775 (C=O str.), 1625–1620 $cm^{-1}$ (C=N str.).

(ii) A series of novel salts (Table 3), the arylamidoxime 4-(3-aryl-1,2,4-oxadiazol-5-yl)hexafluoro-n-butyrates (IX) (R = H, *p*-$CH_3$, *m*-$CH_3$), have been produced in three different ways.



(IX)

Fig. 1. The IR spectra of (a) *O,O'*-hexafluoroglutaryl di(benzamidoxime) and (b) benzamidoxime 4-(3-phenyl-1,2,4-oxadiazol-5-yl)hexafluoro-n-butyrate.


Wavelength (microns)
KBr disc
KBr disc
Transmittance (%)
Transmittance (%)
cm⁻¹

If after the *O,O'*-hexafluoroglutaryl di(benzamidoximes) (VIII) (R = H, *p*-$CH_3$, *m*-$CH_3$) had been collected, the reaction solution was treated with a further quantity of arylamidoxime and pyridine, yields of salts (IX) (R = H, *p*-$CH_3$, *m*-$CH_3$) up to 20% were obtained. Heating *O,O'*-hexafluoroglutaryl di(arylamidoximes) (VIII) (R = H, *p*-$CH_3$, *m*-$CH_3$) in the presence of anhydrous DMF or pyridine at 70°, or in refluxing aqueous ethanol, gave almost quantitative yields of compounds (IX). Alternatively, 65–70% yields were obtainable by the reaction of arylamidoximes and hexafluoroglutaryl chloride in pyridine solution at room temperature.

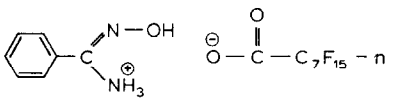
TABLE 3

ARYLAMIDOXIME 4-(3-ARYL-1,2,4-OXADIAZOL-5-YL)HEXAFLUORO-n-BUTYRATES (IX)

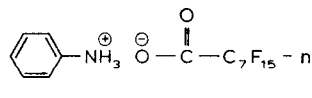
| R | Yield (%) | M.p. (°C) | Equivalent: Req'd. | Equivalent: Found | Analysis: Calcd. % C | H | F | N | Found % C | H | F | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H(nc) | 21[a] 65[b] | 144–145 | 476 | 476 | 47.9 | 3.0 | 23.9 | 11.8 | 48.1 | 3.2 | 23.9 | 11.8 |
| *p*-$CH_3$(nc) | 17[a] 68[b] | 159–160 | 504 | 510 | 50.0 | 3.6 | 22.6 | 11.1 | 50.2 | 3.3 | 22.3 | 10.9 |
| *m*-$CH_3$(nc) | 17[a] 66[b] | 139–139.5 | 504 | 508 | 50.0 | 3.6 | 22.6 | 11.1 | 49.8 | 3.6 | 22.3 | 10.8 |

[a] Reaction in ether solution.
[b] Reaction in pyridine solution.

The salts were characterised by their elemental analyses, equivalent weights and the formation[9] of the parent acids and various derivatives. Infrared spectra of all three salts were very similar and that for benzamidoxime 4-(3-phenyl-1,2,4-oxadiazol-5-yl)hexafluoro-n-butyrate (Fig. 1) is typical, the strong sharp band at 3400 $cm^{-1}$ (OH stretching) and the broad complex of bands between 3200 and 2400 $cm^{-1}$ being characteristic. It is noteworthy that the salt (X) from benzamidoxime and pentadecafluoro-n-octanoic acid had a very similar spectrum in this region, whilst that for compound (XI) was significantly different.



(X)

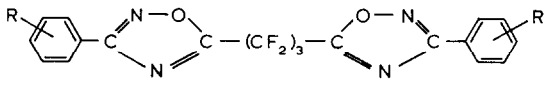


(XI)

The proton nuclear magnetic resonance (NMR) spectrum of compound (IX) (R = H) in freshly dried DMF showed two weak signals which were attributed to $NH_3^{\oplus}$ and OH. On addition of a few drops of water the hydroxyl resonance dis-

appeared, this being due to the rapid exchange of water protons with the amidoxime hydroxyls[10]. Evidence for the presence of the 1,2,4-oxadiazole ring in compounds (IX) came from a comparison of the ultraviolet (UV) spectrum of compound (IX) (R = H) ($\lambda_{max.}$ = 2280; $\varepsilon$ = 19 000) with those of 5-perfluoroalkyl- and perfluoroalkylene-3-phenyl-1,2,4-oxadiazoles (Table 6). The salts were strong electrolytes in DMF solution, benzamidoxime 4-(3-phenyl-1,2,4-oxadiazol-5-yl)hexafluoro-n-butyrate ((IX); R = H) having a molar conductance at 18° of 23.1 $ohm^{-1}cm^2$ compared with a value for sodium nitrate at 25° of 61.6 $ohm^{-1}cm^2$.

(iii) The fully cyclised materials (XII) (R = H, *p*-$CH_3$, *m*-$CH_3$) (Table 4), which on the basis of the easy synthesis of the 5-perfluoroalkyl-3-phenyl-1,2,4-oxadiazoles were initially expected, were obtained in only 10–12% yield from the reaction of the arylamidoximes and hexafluoroglutaryl chloride in pyridine at room temperature. However, cyclisation of the *O,O'*-hexafluoroglutaryl di(amidoximes) (VIII) by heating at 250° in the presence of phosphorus pentoxide gave 70–80% yields of compounds (XII).



(XII)

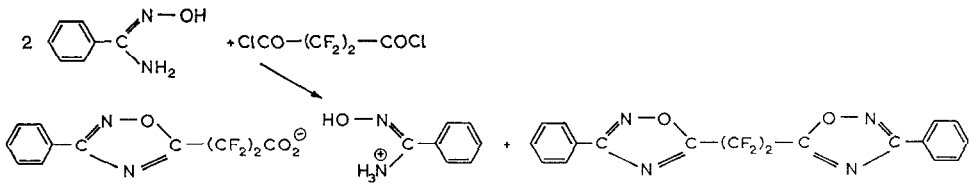
TABLE 4

1,3-BIS(3-ARYL-1,2,4-OXADIAZOL-5-YL)HEXAFLUOROPROPANES[a] (XII)

| R | Yield (%) | M.p. (°C) | Analysis: Calcd. % C | H | F | N | Found % C | H | F | N |
|---|---|---|---|---|---|---|---|---|---|---|
| H(nc) | 10[b] 76[c] | 63–64 | 51.8 | 2.3 | 25.9 | 12.7 | 51.9 | 2.4 | 25.9 | 12.6 |
| *p*-$CH_3$(nc) | 12[b] 72[c] | 112–113 | 53.90 | 3.0 | 24.3 | — | 54.0 | 3.0 | 24.3 | — |
| *m*-$CH_3$(nc) | 12[b] 76[c] | 64 | 53.9 | 3.0 | 24.3 | — | 54.3 | 3.0 | 24.2 | — |

[a] $\nu_{max.}$ = 1590–1500 (C=N str.), 1220–1100 $cm^{-1}$ (C–F str.).
[b] By reaction of arylamidoxime and hexafluoroglutaryl chloride in pyridine solution at room temperature.
[c] By cyclisation of *O,O'*-perfluoroglutaryl di(arylamidoximes) ($P_2O_5$/250°).

(b) Tetrafluorosuccinyl chloride gave two products:
Benzamidoxime 3- (3-phenyl-1,2,4-oxadiazol-5-yl)tetrafluoropropionate (XIII) was obtained in approximately 60% yield when the reaction was performed at room temperature in ether solution containing an equivalent of pyridine, or in pyridine solution alone. In either solution, however, a small quantity (6–16%) of the fully cyclised 1,2-bis-(3-phenyl-1,2,4-oxadiazol-5-yl)tetrafluoroethane (XIV) was also obtained.

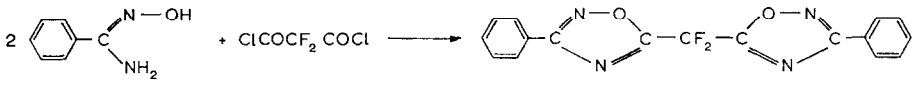


(XIII) (XIV)

Separation of these two compounds was made possible by the solubility of the salt (XIII) in hot water.

(c) Difluoromalonyl chloride gave one product:

Reaction with benzamidoxime in either ether solution containing an equivalent of pyridine, or in pyridine solution alone, gave the fully cyclised compound bis(3-phenyl-1,2,4-oxadiazol-5-yl)difluoromethane (XV) as by far the major product.

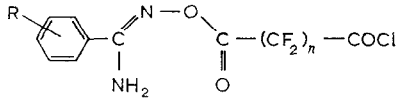


(XV)

The three fully cyclised materials (XII) (R = H), (XIV) and (XV) showed an interesting variation in melting point, the difluoromethylene-linked compound melting at 67–68°, the tetrafluoroethylene-linked one at 150–151° and the hexafluoropropylene-linked one at 64°.

The rather unexpected formation of the arylamidoxime salts from hexafluoroglutaryl and tetrafluorosuccinyl chlorides does appear to preclude extension of the arylamidoxime–perfluorodiacyl chloride reaction into a polymer-forming one; Brown[11] was similarly unable to prepare polymers by the reaction of hexafluoroglutaryl chloride and hexafluoroglutarodiamidoxime. However, the salts have led, *via* the corresponding perfluorocarboxylic acids, to a novel group of 1,2,4-oxadiazolyl perfluoro-olefins[9].

The formation of the salts might be readily explained by assuming the diacyl chloride to have only half-reacted, giving an intermediate (XVI):

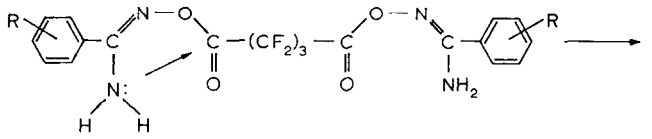


(XVI)

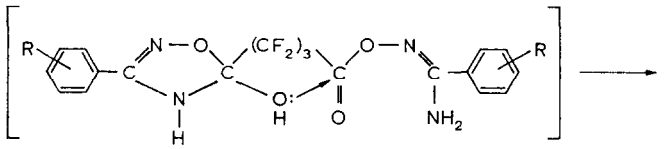
The ease of cyclisation of such a fluoroalkyl-substituted intermediate has already been established, and the water thus evolved would hydrolyse the remaining acid chloride group. The resulting acid could subsequently react with further arylamidoxime to form the arylamidoxime salts. However, the possibility of forming the salts from the open-chain compounds (VIII), and the fact that there is no strong

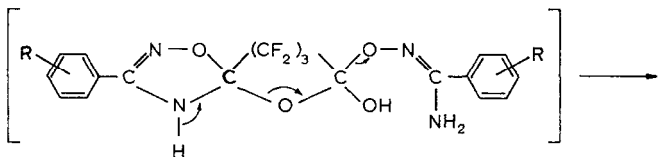
evidence for such salts from difluoromalonyl chloride, necessitates an additional explanation.

Thus the diversity of products may be explained by postulating 5- and 6-membered ring transition-state complexes. It seems possible that the conversion, in polar solvents, of *O,O'*-hexafluoroglutaryl di(arylamidoximes) (VIII) (R = H, *p*-$CH_3$, *m*-$CH_3$) into arylamidoxime salts (IX) (R = H, *p*-$CH_3$, *m*-$CH_3$) might involve the following reaction sequence:

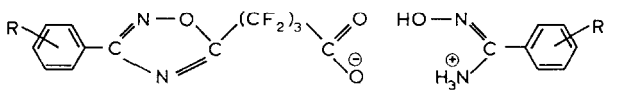


(VIII)





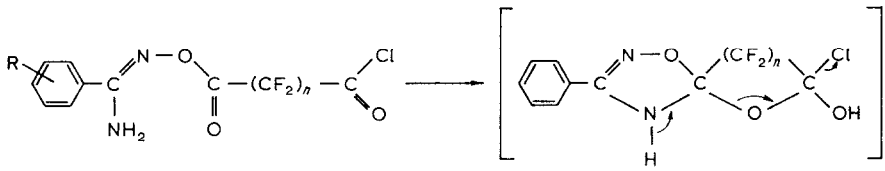
(XVII)



(IX)

The relatively strong electron-withdrawing nature of the perfluoroalkyl chain facilitates cleavage of the C–O–(N) bond and leads to the formation of the arylamidoxime salts. If it is assumed that the *O,O'*-perfluoroalkyl di(arylamidoximes) (VIII) are intermediates, even in those reactions performed in pyridine solution, then the above mechanism could apply for both hexafluoroglutaryl and tetrafluorosuccinyl chlorides.

A further possibility is the formation of 5- or 6-membered ring transition-state complexes of the type (XVII) from the half-reacted intermediate (XVI) *via* structure (XVIII), again the resulting acid reacting with further arylamidoxime to give arylamidoxime salt.



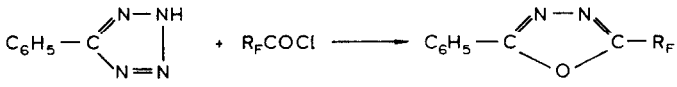
(XVI) (XVIII)

Similar transition-state complexes involving a strained 4-membered ring are less likely, which could explain the different behaviour of difluoromalonyl chloride towards arylamidoximes.

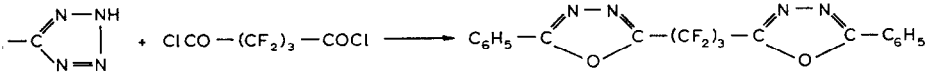
*1,3,4-Oxadiazoles*

2,5-Bis(perfluoroalkyl)-1,3,4-oxadiazoles and poly(perfluoroalkylene-1,3,4-oxadiazoles) have already been synthesised by two general techniques: dehydration of the corresponding mono- or di-hydrazide[12–14] and reaction[15,16] of the perfluoroalkyltetrazole with perfluoromono- or di-acyl chlorides according to the method pioneered by Huisgen *et al.*[17].

In the current work, the latter technique was successfully employed using 5-phenyltetrazole (XIX) and a variety of perfluoroacyl chlorides in pyridine solution at 90°, to give the 5-perfluoroalkyl-2-phenyl-1,3,4-oxadiazoles (XX) ($R_F$ = $C_2F_5$, n-$C_3F_7$ and n-$C_7F_{15}$) and 1,3-bis(2-phenyl-1,3,4-oxadiazol-5-yl)-hexafluoropropane (XXI) (Table 5).



(XIX) (XX)



(XXI)

These compounds all have melting points above the comparable 2,5-bis-(perfluoroalkyl)-1,3,4-oxadiazoles[12,13], which are mobile liquids at room temperature, and in all cases they are higher melting than the analogous 1,2,4-oxadiazoles (Table 1).

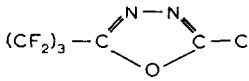
*Spectral studies*

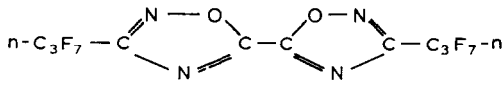
A study of the UV and NMR spectra of a series of non-fluorinated 1,2,4-oxadiazoles has led[18] to the conclusion that the two double bonds in the ring, though conjugated, are not part of an aromatic system. Similarly, the UV spectra of 2,5-bis(perfluoroalkyl)-1,3,4-oxadiazoles[12] or 3,5-bis(perfluoroalkyl)-1,2,4-oxadiazoles[5] do not show any absorption in the 2200–3400 Å region, which might imply aromatic delocalisation. However, unlike the other disubstituted perfluoro-

alkyl-oxadiazoles, 3,3′-bis(heptafluoro-n-propyl)bi-1,2,4-oxadiazol-5-yl (XXII) and 2,2′-bis(heptafluoro-n-propyl)bi-1,3,4-oxadiazol-5-yl (XXIII) were shown[5] to have absorption maxima at 2320 (log $\varepsilon_{max.}$ = 4.04) and 2340 Å (log $\varepsilon_{max.}$ = 4.09), respectively.

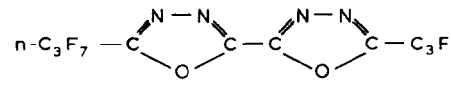
TABLE 5

5-PERFLUOROALKYL- AND PERFLUOROALKYLENE-2-PHENYL-1,3,4-OXADIAZOLES (XX) AND (XXI)

| $R_F$ | Yield (%) | M.p. (°C) or b.p. (°C/mmHg) | Analysis: Calcd. % C | H | F | N | Found % C | H | F | N |
|---|---|---|---|---|---|---|---|---|---|---|
| $C_2F_5$(nc) | 80 | 54–56/0.1 | 45.5 | 1.9 | 36.0 | 10.6 | 45.3 | 1.7 | 36.2 | 10.3 |
| n-$C_3F_7$(nc) | 81 | 29 | 42.1 | 1.6 | 42.3 | 8.9 | 41.8 | 1.6 | 42.3 | 8.6 |
| n-$C_7F_{15}$(nc) | 74 | 56–57 | 35.0 | 1.0 | 55.4 | 5.4 | 35.4 | 1.0 | 55.2 | 5.7 |
|  | 57 | 101–102 | 51.8 | 2.3 | 25.9 | 12.7 | 52.4 | 2.4 | 25.8 | 12.8 |



(XXII)

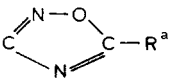


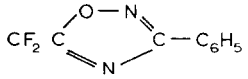
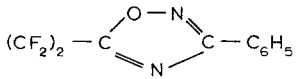
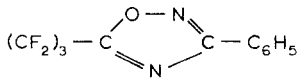
(XXIII)

It was suggested that the occurrence of absorptions in the UV is due to increased conjugation in such compounds, due specifically to the N=C–N=C–C=N–C=N and C=N–N=C–C=N–N=C chromophores. The interaction of a phenyl group in the 2 position of the 1,3,4-oxadiazole or the 3 position of the 1,2,4-oxadiazole rings leads similarly to absorptions in the near-UV (Tables 6 and 7). The 5-perfluoroalkyl- and perfluoroalkylene-3-phenyl-1,2,4-oxadiazoles absorb at shorter wavelengths than both compound (XXII) (by 95–60 Å) and the 5-perfluoroalkyl- and perfluoroalkylene-2-phenyl-1,3,4-oxadiazoles (by 315–275 Å); in both cases the conjugated chain length of the 3-phenyl-1,2,4-oxadiazoles is shorter, having three rather than four double bonds. However, the 5-perfluoroalkyl- and perfluoroalkylene-2-phenyl-1,3,4-oxadiazoles absorb at considerably longer wavelengths (by 200 Å) than compound (XXIII), although both systems have four conjugated double bonds. Probably an enhanced degree of interaction between benzene and 1,3,4-oxadiazole rings, due to the π-electron delocalisation in the benzene ring, is responsible. Those 1,2,4-oxadiazoles having perfluoroalkylene groups between identical conjugated systems, namely (XII) (R = H), (XIV) and (XV), and the 1,3,4-compound (XXI), all absorb at the same wavelength, but with twice the intensity of those compounds containing only one such conjugated system. This is expected, since the perfluoroalkylene groups entirely break the conjugation between the two chromophores.

A feature of the 5-perfluoroalkyl-2-phenyl-1,3,4-oxadiazoles is the red-shift (65 Å) observed on replacement of the proton in position 5 of the oxadiazole ring; this is in contrast to the blue shift observed on replacement of the proton in position 5 of the 1,2,4-oxadiazole ring, which blue shift is as much as 200 Å in the pentafluoro-allyl[9] derivative.

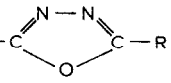
TABLE 6

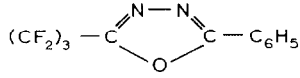
UV SPECTRA OF 

| R | $\lambda_{max.}$ (Å) | ε |
|---|---|---|
| H[b,c] | 2380 | 14000 |
| $C_2F_5$ | 2225 | 9650 |
| n-$C_3F_7$ | 2235 | 10900 |
| n-$C_7F_{15}$ | 2235 | 11100 |
|  | 2260 | 23100 |
|  | 2250 | 22200 |
|  | 2265 | 19000 |
| $CF_2CF{=}CF_2$[d] | 2180 | 12000 |

[a] In ethanol solution.
[b] In diethyl ether solution.
[c] Ref. 18.
[d] Ref. 9.

TABLE 7

UV SPECTRA OF 

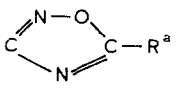
| R | $\lambda_{max.}$ (Å) | ε |
|---|---|---|
| H[b] | 2475 | 18600 |
| $C_2F_5$ | 2540 | 18100 |
| n-$C_3F_7$ | 2540 | 22400 |
| n-$C_7F_{15}$ | 2540 | 18200 |
|  | 2540 | 39400 |

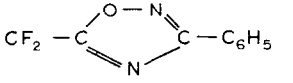
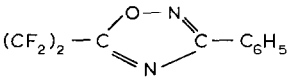
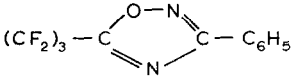
[a] In ethanol solution.
[b] Ref. 17.

*Thermal stabilities*

The superior thermal stability of the 1,3,4- over the 1,2,4-oxadiazole ring system observed[19] in the non-fluorinated model compounds and polymers is likewise exhibited by the perfluoroalkyl-substituted systems (Tables 8 and 9). Moreover, the perfluoroalkyl-1,2,4-oxadiazoles are considerably less stable than their non-fluorinated analogues, the thermal decomposition points ($T_D$) of which range from 260–280°.

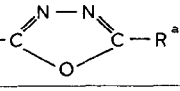
TABLE 8

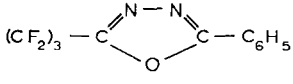
DECOMPOSITION TEMPERATURES OF  [a]

| R | $T_D$ (°C)[b] |
|---|---|
| $C_2F_5$ | 197[c] |
| n-$C_3F_7$ | 209[c] |
| n-$C_7F_{15}$ | 239 |
|  | 203 |
|  | 209 |
|  | 223 |

[a] By isotensiscope.
[b] $T_D$ defined as the temperature at which the rate of pressure rise reaches 0.88 mmHg $min^{-1}$.
[c] Measured at 3 atmospheres pressure.

TABLE 9

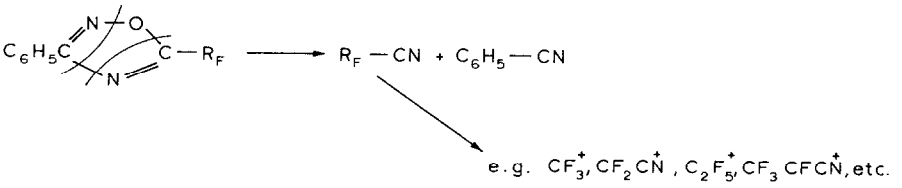
DECOMPOSITION TEMPERATURES OF  [a]

| R | $T_D$ (°C) |
|---|---|
| $C_2F_5$ | >237[b] |
| n-$C_3F_7$ | >245[b] |
| n-$C_7F_{15}$ | >290[b] |
|  | ~305 |

[a] By isotensiscope.
[b] No decomposition below the boiling point.

From the results shown in Table 9 it is not surprising that other workers[12,13] have found the stability of the 2,5-bis(perfluoroalkyl)-1,3,4-oxadiazoles to be high; Brown *et al.*[12] have reported no decomposition on heating such compounds in an evacuated sealed glass tube for 15 h at 350° and for 1 h at 400°. The claim[5] that 3,5-bis(perfluoroalkyl)-1,2,4-oxadiazoles are similarly stable is surprising; presumably decomposition was measured by changes which were not as sensitive as the isotensiscope method.

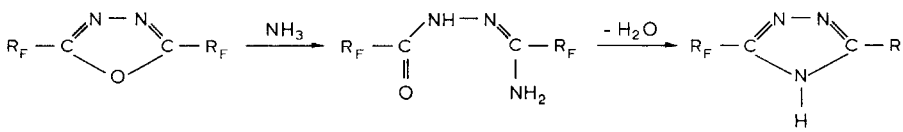
The mass spectra of a number of these perfluoroalkyl and perfluoroalkylene-1,2,4- and 1,3,4-oxadiazoles have already been reported[20–22] and a study made of the electron impact fragmentation behaviour. A mass-spectral examination of the products resulting from the thermal decomposition of 5-perfluoroalkyl-3-phenyl-1,2,4-oxadiazoles (VI) ($R_F$ = $C_2F_5$, n-$C_3F_7$ and n-$C_7F_{15}$) between 260 and 290° has indicated the following fragmentation behaviour, which shows a difference from that on electron impact:



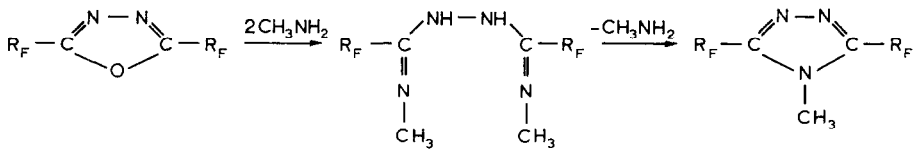

Although, as with hydrocarbon aliphatic nitriles, no parent ions were shown by the perfluoroalkyl nitriles, the principle fragment ions indicated their transient existence. Above 300°, a more extensive decomposition occurred and phenyl isocyanate, benzonitrile and carbon dioxide were identified. No exact pyrolysis data is available for the perfluoroalkyl-1,3,4-oxadiazoles, but no measurable decomposition was detected below 300°.

*Nucleophilic attack*

The effect of a nucleophilic reagent such as methylamine on the phenyl-substituted perfluoroalkyl-1,3,4- and 1,2,4-oxadiazoles has also been studied. Brown and Cheng[23] have already shown that 2,5-bis(perfluoroalkyl)-1,3,4-oxadiazoles are readily attacked by both ammonia and methylamine to give by ring opening the intermediates (XXIV) and (XXVI) which, by dehydration or deamination, give the corresponding triazoles (XXV) and (XXVII).

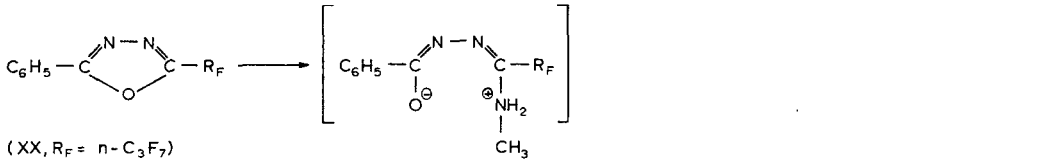



(XXIV) (XXV)

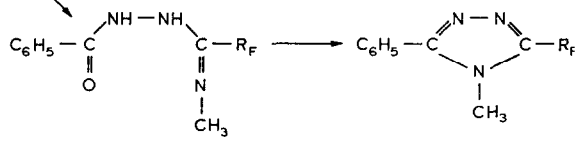


(XXVI) (XXVII)

Reaction of refluxing methylamine with 5-heptafluoropropyl-2-phenyl-1,3,4-oxadiazole (XX) ($R_F$ = n-$C_3F_7$) has given a product of structure (XXVIII); contrary to Brown and Cheng's observation[23] for the bis(perfluoroalkyl)-1,3,4-oxadiazoles, only one molecule of methylamine attacks the ring, presumably at the ring carbon attached to the perfluoroalkyl group:



(XX, $R_F$ = n-$C_3F_7$)



(XXVIII) (XXIX)

Infrared and analytical data for compound (XXVIII) confirmed its structure. It was dehydrated by heating in the presence of phosphorus pentoxide to give the triazole (XXIX).

5-Pentafluoro-n-propyl-3-phenyl-1,2,4-oxadiazole (VI) (R = n-$C_3F_7$) was, however, unaffected after several hours in refluxing methylamine.

## EXPERIMENTAL

### *Starting materials*

Pentadecafluoro-octanonitrile, b.p. 101–102° (Found: C, 24.1; F, 71.7; N, 3.2%. Calcd. for $C_8F_{15}N$: C, 24.3; F, 72.1; N, 3.5%) was prepared by the methods of Swarts[24] and Gilman and Jones[25] for other perfluoroalkanonitriles, from the commercially available carboxylic acid *via* the esters and amides. Perfluoromonoacyl chlorides and 5-phenyltetrazole were prepared by well-authenticated methods.

### *Preparation of pentadecafluoro-n-octanamidoxime*

Hydroxylamine hydrochloride (3.7 g, 50 mmole) dissolved in water (30 ml) was stirred with sodium carbonate (2.7 g, 25 mmole) until carbon dioxide had

ceased to be evolved. Pentadecafluoro-octanonitrile (19.7 g, 50 mmole) in ethanol (50 ml) was added, and then further ethanol until a homogeneous mixture was obtained. There was an immediate exothermic reaction and colourless, crystalline plates precipitated; the mixture was stirred for a further 2 h without external heating. The solid was filtered off, washed with water and dried *in vacuo* ($P_2O_5$) to give pentadecafluoro-n-octanamidoxime (19.8 g, 93%), m.p. 122–123.5°. Recrystallisation from aqueous ethanol gave m.p. 126–127° (lit.[5] m.p. 121–122.5°). (Found: C, 22.5; H, 1.1; F, 66.7; N, 6.5%. Calcd. for $C_7H_3F_{15}N_2O$: C, 22.4; H, 0.7; F, 66.6; N, 6.5%.)

*Reactions of pentadecafluoro-n-octanamidoxime*

*(i) With hexafluoroglutaryl chloride*

Pentadecafluoro-n-octanamidoxime (8.6 g, 20 mmole) was dissolved in pyridine (6 ml) and DMF (20 ml), the solution being stirred under nitrogen with the exclusion of atmospheric moisture. Hexafluoroglutaryl chloride (2.8 g, 10 mmole) in dry DMF (10 ml) was slowly added; a white solid was precipitated and a slight exotherm noted. The mixture was then stirred at room temperature for 16 h. The precipitate was collected, washed and dried ($P_2O_5$) *in vacuo* to give *O,O'*-hexafluoroglutaryl di(pentadecafluoro-n-octanamidoxime) (III) (nc) (1.8 g, 16.5%), m.p. 125–130°; after recrystallisation from ethanol/water, m.p. 131–132°. (Found: C, 23.7; H, 1.0; F, 63.9; N, 5.9%. Calcd. for $C_{21}H_4F_{36}N_4O_4$: C, 23.7; H, 0.4; F, 64.5; N, 5.3%.) The filtrate was concentrated and, on addition of water, unreacted pentadecafluoro-n-octanamidoxime (3.9 g) was precipitated.

*O,O'*-Hexafluoroglutaryl di(pentadecafluoro-n-octanamidoxime) (1.5 g, 1 mmole) was thoroughly mixed with an excess of phosphorus pentoxide and heated at 200–250° for 8 h with the exclusion of atmospheric moisture. The solid product was extracted with dry ether, the ether extract dried ($MgSO_4$) and the solvent removed to leave a straw-coloured oil (0.6 g). The IR and mass spectra of this oil indicated it to be the dicyclised 1,3-bis(3-pentadecafluoro-n-heptyl-1,2,4-oxadiazol-5-yl)hexafluoropropane (IV) (nc).

*(ii) With diphenyl isophthalate*

Diphenyl isophthalate (3.0 g, 10 mmole) dissolved in DMF (40 ml) was added with stirring to a solution of pentadecafluoro-n-octanamidoxime (8.2 g, 20 mmole) in DMF (40 ml) with the exclusion of atmospheric moisture and heated to 100–120° for 12 h. The colourless, crystalline plates which appeared on cooling were collected, washed with DMF and dried ($P_2O_5$) *in vacuo* to give 1,3-bis(3-perfluoro-n-heptyl-1,2,4-oxadiazol-5-yl)benzene (V) (nc) (1.1 g, 11.5%), m.p. 100–101°; recrystallisation from ethanol gave m.p. 101–102°. (Found: C, 31.0; H, 0.5; F, 60.3; N, 5.9%. Calcd. for $C_{24}H_4F_{30}N_4O_2$: C, 30.8; H, 0.4; F, 60.0; N, 5.9%.) Further heating of the filtrate for 12 h did not yield more of compound (V).

*Preparation of 5-perfluoroalkyl-3-phenyl-1,2,4-oxadiazoles*

Benzamidoxime (100 mmole) was dissolved in anhydrous ether (200 ml) and pyridine (100 mmole) and the solution, which was cooled to 0°, stirred under nitrogen with the exclusion of atmospheric moisture. Perfluoroacyl chloride (100 mmole) was added drop-wise *via* a cooled (—70°) funnel; a dense white solid immediately precipitated and progressively thickened. The solution was then allowed to warm to room temperature for 2 h when there was a marked reduction in the amount of precipitate. The solution was refluxed for 2 h, cooled to room temperature and filtered. Removal of the solvent left an oil, or low-melting solids. These products were purified by distillation or recrystallisation from ethanol (Table 1).

*Reaction of arylamidoximes with hexafluoroglutaryl chloride*

*(i) In ether solution*

The arylamidoxime (100 mmole) was dissolved in anhydrous ether (850 ml) and pyridine (100 mmole), and the solution stirred under nitrogen with the exclusion of atmospheric moisture. Hexafluoroglutaryl chloride (50 mmole) was added drop-wise; a dense, white precipitate formed immediately with no apparent exotherm. The reaction mixture was stirred at room temperature for 20 h and then filtered. The washed precipitate was dried ($P_2O_5$) *in vacuo* to give *O,O'*-hexafluoroglutaryl di(arylamidoximes) (VIII). These products (Table 2) were purified by careful precipitation (water) from DMF solution.

To the filtrate was added a solution of arylamidoxime (0.05 equiv.) in ether (200 ml) and pyridine (0.1 equiv.). A further dense precipitate immediately appeared, but then mainly re-dissolved; after being stirred for 3 h at room temperature, the solution was filtered from a very small tacky precipitate and the ether distilled. The remaining pyridine solution was poured on to ice/hydrochloric acid mixture to give a granular solid. This solid was washed and dried ($P_2O_5$) *in vacuo* to give the arylamidoxime 4-(3-aryl-1,2,4-oxadiazol-5-yl)hexafluoro-n-butyrate (IX) (nc). These products (Table 3) were purified by recrystallisation from water or ethanol/water.

*(ii) In pyridine solution*

The arylamidoxime (100 mmole) was dissolved in pyridine (1 l) and the solution stirred under nitrogen with the exclusion of moisture. Hexafluoroglutaryl chloride (50 mmole) was added slowly: there was no precipitate, but an exotherm was observed and controlled at 40° by external cooling. The solution was stirred at 40° for 3 h; most of the pyridine was then removed by distillation under reduced pressure and the residual oil poured on to ice/hydrochloric acid mixture. The granular solid thus obtained was collected, washed and dried ($P_2O_5$) *in vacuo*. Extraction with hot water gave the salts (IX) (Table 3). The water-insoluble products were purified by crystallisation from ethanol and found to be 1,3-bis-(3-aryl-1,2,4-oxadiazol-5-yl)hexafluoropropanes (XII) (nc) (Table 4).

*Reaction of benzamidoxime with tetrafluorosuccinyl chloride*

*(i) In ether solution*

Conditions used in the reaction of hexafluoroglutaryl chloride with arylamidoximes were repeated. The products obtained were benzamidoxime 3-(3-phenyl-1,2,4-oxadiazol-5-yl)tetrafluoropropionate (XIII) (nc) (59%), m.p. 145–146° (Found: C, 51.0; H, 3.3; F, 17.8; N, 13.1%, equiv. 424. Calcd. for $C_{18}H_{14}F_4N_4O_4$: C, 50.9; H, 3.3; F, 17.8; N, 13.1%, equiv. 426) and 1,2-bis(3-phenyl-1,2,4-oxadiazol-5-yl)tetrafluoroethane (XIV) (nc) (6%), m.p. 150–151° (Found: C, 55.5; H, 2.9; F, 14.2; N, 19.4%. Calcd. for $C_{18}H_{10}F_4N_4O_2$: C, 55.4; H, 2.6; F, 14.4; N, 19.5%).

*(ii) In pyridine solution*

Conditions used in the reaction of hexafluoroglutaryl chloride with arylamidoximes were repeated to give (XIII) (58%) and (XIV) (16%).

*Reaction of benzamidoxime with difluoromalonyl chloride*

*(i) In ether solution*

Conditions used in the previous experiments were repeated to give bis(3-phenyl-1,2,4-oxadiazol-5-yl)difluoromethane (XV) (nc) (57%) m.p. 63–64° (Found: C, 60.1; H, 3.1; F, 11.2; N, 16.6%. Calcd. for $C_{17}H_{10}F_2N_4O_2$: C, 60.0; H, 2.9; F, 11.2; N, 16.5%); $\nu_{max.}$ 1600–1520 (C=N ring str.), 1350 ($C_2N_2O$ ring str.), 1200–1100 $cm^{-1}$ (C–F str.).

*(ii) In pyridine solution*

Conditions used in the previous experiments were repeated to give (XV) (58%).

*Preparation of 5-perfluoroalkyl- and perfluoroalkylene-2-phenyl-1,3,4-oxadiazoles*

5-Phenyltetrazole (100 mmole) was dissolved in pyridine (100 ml) and the solution cooled below 5° and stirred under nitrogen with the exclusion of atmospheric moisture. A perfluoromonoacyl chloride ($R_FCOCl$; $R_F$ = $C_2F_5$, n-$C_3F_7$, n-$C_7F_{15}$; 100 mmole) or hexafluoroglutaryl chloride (50 mmole) was added dropwise *via* a cooled funnel; an immediate exotherm was observed but the solution temperature was not at this stage allowed to rise above 40°. After complete addition of the acyl chloride, the solution, which by then had turned to a deep red colour, was heated at 90–95° for 3–5 h. The solution was cooled and poured on to an excess of ice/hydrochloric acid solution giving tacky solids in all cases except with heptafluoropropionyl chloride. These 5-perfluoroalkyl- and perfluoroalkylene-2-phenyl-1,3,4-oxadiazoles (Table 5) were purified by distillation ((XX); $R_F$ = $C_2F_5$), sublimation ((XX); $R_F$ = n-$C_3F_7$) or recrystallisation from ethanol ((XX); R = n-$C_7F_{15}$; and (XXI)).

*Reaction of 5-perfluoropropyl-2-phenyl-1,3,4-oxadiazole with methylamine*

5-Perfluoro-n-propyl-2-phenyl-1,3,4-oxadiazole (4.4 g, 14 mmole) was placed in a 50 ml flask equipped with a condenser cooled with solid carbon dioxide. Methylamine (5.0 g, 170 mmole) was condensed into the flask and the oxadiazole allowed to react with the refluxing methylamine for 3 h. During the reaction a deep yellow colour was produced. After removal of the excess of methylamine, the residual solid was dried ($P_2O_5$) *in vacuo* to give 1-(*N*-methylheptafluoro-n-butyrimidoyl)-2-benzoylhydrazine (XXVIII) (nc) (4.3 g, 89%), m.p. 174–175°, and after recrystallisation from DMF, m.p. 174–175° (Found: C, 41.9; H, 2.9; F, 39.4; N, 11.9%. Calcd. for $C_{12}H_{10}F_7N_3O$: C, 41.7; H, 2.9; F, 38.6; N, 12.2%); $\nu_{max.}$ 3250 (N–H str.), 1660 $cm^{-1}$ (C=O str.).

1-(*N*-Methylheptafluoro-n-butyrimidoyl)-2-benzoylhydrazine (3.5 g, 100 mmole) was mixed with phosphorus pentoxide in a sublimator and heated at 150° for 3 h. A vacuum was then applied and 3-heptafluoropropyl-4-methyl-5-phenyl-1,2,4-triazole (XXIX) (nc) sublimed at 105–110°/0.1 mmHg as a white solid (2.0 g, 62%), m.p. 133–134°; after recrystallisation from ethanol m.p. 135–136° (Found: C, 44.5; H, 2.6; F, 39.6; N, 12.8%. Calcd. for $C_{12}H_8F_7N_3$: C, 44.1; H, 2.4; F, 40.6; N, 12.8%); $\nu_{max.}$ 3060–3030 (C–H str.), 1490–1460 (C=N str.?), 1240–1100 $cm^{-1}$ (C–F str.).

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REFERENCES

1 J. P. CRITCHLEY *et al.*, forthcoming publications.
2 J. P. CRITCHLEY, V. C. R. MCLOUGHLIN, J. THROWER AND I. M. WHITE, *Brit. Polymer J., 2* (1970) 288.
3 J. M. BARTON AND J. P. CRITCHLEY, *Polymer, 11* (1970) 212.
4 J. P. CRITCHLEY, E. J. P. FEAR AND J. S. PIPPETT, *Chem. Ind. (London)*, (1964) 806.
5 H. C. BROWN AND C. R. WETZEL, *J. Org. Chem., 30* (1965) 3734.
6 I. L. KNUNYANTS, M. P. KRASUSKAYA AND D. P. DEL'TSOVA, *Izvest. Akad. Nauk SSSR, 3* (1966) 577.
7 C. L. BELL, C. N. V. NAMBURY AND L. BAUER, *J. Org. Chem., 29* (1964) 2873.
8 G. RAPPAPORT, M. HAUPTSCHEIN, J. F. O'BRIEN AND R. FILLER, *J. Amer. Chem. Soc., 75* (1953) 2695.
9 J. P. CRITCHLEY AND J. S. PIPPETT, *J. Fluorine Chem.*, following paper.
10 H. E. UNGNADE, L. W. KISSINGER, A. NARATH AND D. C. BARHAM, *J. Org. Chem., 28* (1963) 134.
11 H. C. BROWN, *USAF Mat. Lab. Tech. Rep. ML-TDR-64-142, Pt. VI*, Astia Document No. 853,950, 1969.
12 H. C. BROWN, M. T. CHENG, L. J. PARCELL AND D. PILIPOVICH, *J. Org. Chem., 26* (1961) 4407.
13 W. J. CHAMBERS AND D. D. COFFMAN, *J. Org. Chem., 26* (1961) 4410.
14 M. P. KRASUSKAYA, D. P. DEL'TSOVA AND I. L. KNUNYANTS, *Izvest. Akad. Nauk SSSR, Otdel. Khim. Nauk, 11* (1965) 2059.

15 H. C. BROWN AND R. J. KASSAL, *Amer. Chem. Soc., Div. Fluorine Chem., Abstracts, 20K*, 40 (1964).
16 E. I. DU PONT DE NEMOURS, *B.P.*, 988119 (1965); *Chem. Abstr., 63* (1965) 700.
17 R. HUISGEN, J. SAUER, H. J. STURM AND J. H. MARKGRAF, *Chem. Ber., 93* (1960) 2106.
18 C. MOUSSEBOIS AND J. F. M. OTT, *Helv. Chim. Acta, 47* (1964) 942.
19 J. P. CRITCHLEY AND J. S. PIPPETT, *RAE Technical Report 67057*, 1967.
20 J. L. COTTER, *J. Chem. Soc.*, (1965) 6842.
21 J. L. COTTER, *J. Chem. Soc. (B)*, (1967) 1271.
22 J. L. COTTER AND H. DICKINSON, *Org. Mass Spectrometry, 2* (1969) 1335.
23 H. C. BROWN AND M. T. CHENG, *J. Org. Chem., 27* (1962) 3240.
24 F. SWARTS, *Bull. Classe Sci., Akad. Roy. Belge, 12* (1926) 692.
25 H. G. GILMAN AND R. G. JONES, *J. Amer. Chem. Soc., 65* (1943) 1458.