## Partially Fluorinated Heterocyclic Compounds. Part 13.<sup>1</sup> The Formation of Some Furan Derivatives from Polyfluoroaryl Prop-2-ynyl Ethers

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Pentafluorophenyl prop-2-ynyl ether (1) undergoes isomerisation to 2-fluoromethyl-4,5,6,7-tetrafluorobenzo[b]furan (3) on distillation *in vacuo* over silica at 370 °C. The ether (1) undergoes reaction with benzene and p-xylene at 140 °C to give the 2-arylmethyl-4,5,6,7-tetrafluorobenzo[b]furan derivatives (4) and (8) respectively, while 1,3,4,5,6,7,8-heptafluoro-2-naphthyl prop-2-ynyl ether (2) reacts with the same solvents at 140 °C to give the corresponding 2-arylmethyl-4,5,6,7,8,9-hexafluoronaphtho[2,1-b]furan derivatives (9) and (10) respectively.

THE vapour-phase pyrolyses of polyfluoropyridyl<sup>1</sup> and pentafluorophenyl<sup>2</sup> prop-2-enyl ethers have been shown to give a variety of products via an initial Claisen rearrangement followed by an internal Diels-Alder reaction. In an extension of this work concerning Claisen rearrangements with aromatic substrates containing fluorine in ortho- and para-positions as blocking groups (*i.e.* replacing hydrogen, which would lead to enolisation of the rearranged material) we report now the chemistry of some related prop-2-ynyl ethers: the pentafluorophenyl derivative (1) 2c and the 1,3,4,5,6,7,8-heptafluoro-2-naphthyl derivative (2) prepared from 1,3,4,5,6,7,8heptafluoro-2-naphthol<sup>3</sup> and prop-2-ynyl bromide. It is noteworthy that the first internal Diels-Alder intermediate to be isolated from a Claisen rearrangement utilised 2,6-dimethylphenyl prop-2-vnvl ether.<sup>4</sup>

Distillation of pentafluorophenyl prop-2-ynyl ether (1) through a silica tube packed with quartz wool at 370 °C gave a complex tarry product from which was isolated 2-fluoromethyl-4,5,6,7-tetrafluorobenzo[b]furan (3) (8%) as the major component. The structure of this material, suggested by its simple <sup>1</sup>H and <sup>19</sup>F n.m.r. spectra, was confirmed by the halogen-exchange reaction of 2-bromomethyl-4,5,6,7-tetrafluorobenzo[b]furan <sup>5</sup> with caesium fluoride in sulpholan.



The reaction of the ether (1) with benzene in a sealed tube at 140 °C for 116 h gave HF and a complex mixture from which was isolated one compound (28%). In the absence of model compounds, the elemental analysis,

mass spectral, and n.m.r. data (<sup>1</sup>H and <sup>19</sup>F) of this material could be interpreted in terms of two possible isomers (4) and (5) whose formation could be rationalised mechanistically. However, the problem was resolved by an unambiguous synthesis of (4) from pentafluorobenzyl benzyl ketone (6) [from benzyl chloromethyl ketone <sup>6</sup> and pentafluorophenylcopper <sup>7</sup>] and sodium hydride in dimethylformamide (Scheme 1); <sup>8</sup> even if the enolate formed initially was (7), cyclisation and a proto-





SCHEME 1

tropic shift in acid during the work-up procedure would give  $(4).^9$ 

When pentafluorophenyl prop-2-ynyl ether (1) and p-xylene were heated under reflux for 118 h, 2-(2,5-dimethylbenzyl)-4,5,6,7-tetrafluorobenzo[b]furan (8) (21%) was formed, the structure of which was assigned from its <sup>1</sup>H n.m.r. spectrum on the basis of the chemical shifts of its CH<sub>2</sub> and vinylic CH groups which were essentially identical with those found in (4).

1,3,4,5,6,7,8-Heptafluoro-2-naphthyl prop-2-ynyl ether (2) reacted with benzene at 140 °C over 21 h and with p-xylene at reflux temperature over 20 h to give (9) (64%) and (10) (73%) respectively. The structures of these compounds were assigned to the furan derivatives and not to the respective 2*H*-pyran derivatives (11) and (12), again on the basis of the similarity of the chemical shifts of their CH<sub>2</sub> and vinylic CH groups in the <sup>1</sup>H n.m.r. spectra to the corresponding absorptions in (4). The small deviation of each absorption to lower fields is expected from the larger diamagnetic anisotropy effect of a naphthalene ring on substituents as compared with the effect of a benzene ring. The presence of only one large *peri*  $J_{F-F}$  coupling constant (ca. 60 Hz) in the products was consistent only with the structures (9) and (10); the isomeric products (13) would have had *two* large *peri*  $J_{F-F}$  coupling constants.

These experiments show that the prop-2-ynyl ethers of polyfluoroaromatic systems behave quite differently from the corresponding prop-2-enyl ethers. Previously, substrates having ortho halogens in aryl prop-2-ynyl ethers when heated in n-decane have been shown in each case to give 2-halomethylbenzo[b]furan derivatives among the products.<sup>10</sup> Thus 2,6-dichlorophenyl prop-2ynyl ether gave 2-chloromethyl-7-chlorobenzo[b]furan and 3,8-dichloro-2H-1-benzopyran as the main products; 2,4,6-tribromophenyl prop-2-ynyl ether gave 2-bromomethyl- and 2-methyl-benzo[b]furan; and 1-chloro-(bromo)-2-naphthyl prop-2-ynyl ether gave 2-chloro-(bromo)methylnaphtho[2,1-b]furan accompanied in the





case of the 1-bromo-compound by 2-methylnaphtho[2,1-b]furan. Homolytic cleavage of the C-Cl(Br) bond in the initially formed Claisen rearrangement product was proposed to account for the products in these reactions.

In order to account for the formation of 2-fluoromethyl-4,5,6,7-tetrafluorobenzo[b]furan (3) from pentafluorophenyl prop-2-ynyl ether (1), an analogous isomerisation mechanism can be written (Scheme 2). This remarkable vapour phase reaction requires that following the homolytic cleavage of the aliphatic C-F bond in the Claisen rearrangement product (14), there is a close association between the fluorine atom and the accompanying radical during and following the cyclisation stage. Furthermore, the formation of the 2arylmethyl derivatives (4) and (8) from the reaction of (1) in benzene and p-xylene respectively can be rationlised on the basis of a homolytic substitution mechanism. This necessitates attack on the aromatic solvent by the cyclised radical (15) followed by abstraction of hydrogen from the intermediate complex by the fluorine atom.

An alternative heterolytic process \* for the formation



of the 2-fluoromethyl compound (3) from (14) is shown in Scheme 3. This mechanism also requires a close association between the departing fluorine (as fluoride ion) and the associated organic moiety (16) (a carbocation in this case) in *the vapour phase*. Electrophilic substitution of hydrogen in benzene and p-xylene would then give compounds (4) and (8) respectively. On the evidence presently available it is not possible to distinguish between this mechanism and the mechanism proceeding *via* homolytic cleavage of the aliphatic C-F bond.



The formation of the 2-arylmethyl-4,5,6,7,8,9-hexa-fluoronaphtho[2,1-b]furan derivatives (9) and (10) from 1,3,4,5,6,7,8-heptafluoro-2-naphthyl prop-2-ynyl ether

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(2) with benzene and p-xylene, respectively, must proceed through 1,3,4,5,6,7,8-heptafluoro-1-(propa-1,2-dienyl)naphthalen-2-one [the corresponding 2-(prop-2enyl) ether rearranges to the stable 1,3,4,5,6,7,8-heptafluoro-1-(prop-2-enyl)naphthalen-2-one<sup>11</sup>] and again mechanisms involving both homolytic and heterolytic rupture of the aliphatic C-F bond in this intermediate can be proposed to rationalise the reaction pathway.

## EXPERIMENTAL

1,3,4,5,6,7,8-Heptafluoro-2-naphthyl Prop-2-ynyl Ether (2). --1,3,4,5,6,7,8-Heptafluoro-2-naphthol<sup>3</sup> (14.02 g), anhydrous potassium carbonate (15.70 g), prop-2-ynyl bromide (15.65 g, 80% w/w solution in toluene), and dry acetone (150 ml) were refluxed under nitrogen for 22 h. The mixture was acidified with hydrochloric acid (2M) and extracted with ether. The extracts were dried (MgSO<sub>4</sub>), the solvent evaporated off, and the residue distilled *in vacuo* to give the *ether* (2) (13.31 g, 83%), b.p. 94—97 °C at 0.05 mmHg, m.p. 33—34 °C (Found: C, 50.8; H, 0.7.  $C_{13}H_3F_7O$  requires C, 50.6; H, 0.97%);  $M^+$ , 308.

Pyrolysis of Pentafluorophenyl Prop-2-ynyl Ether (1).<sup>2</sup>c— The ether (1) (5.42 g) was distilled over 10 min from a heated vessel through a silica tube (58 × 1.4 cm) packed with quartz wool heated to 370 °C, into a trap cooled in liquid air connected to a high-vacuum system (0.001 mmHg). The major component in the tarry product was isolated by chromatography on silica (120 × 3.4 cm) (light petroleum [b.p. 40—60 °C] as eluant) followed by preparative t.l.c. on silica (same solvent) to give 2-fluoromethyl-4,5,6,7-tetrafluorobenzo[b]furan (3) (0.41 g, 8%), b.p. 28—29 °C at 0.05 mmHg (Found: C, 48.4; H, 1.7. C<sub>9</sub>H<sub>3</sub>F<sub>5</sub>O requires C, 48.7; H, 1.4%);  $M^+$ , 222;  $\delta_{\rm F}$  (CDCl<sub>3</sub>) 147.3, 160.3, 161.7, 164.1, and 211.4 (t, -CH<sub>2</sub>F) (upfield from internal CFCl<sub>3</sub>);  $\delta_{\rm F}$  (CDCl<sub>3</sub>) 5.42 (d, -CH<sub>2</sub>F), and 7.02 (vinylic CH);  $J_{gen-F,\rm H}$  48.0 Hz.

2-Fluoromethyl-4,5,6,7-tetrafluorobenzo[b]furan (3).—2-Bromomethyl-4,5,6,7-tetrafluorobenzo[b]furan <sup>5</sup> (1.35 g) and dry caesium fluoride (2.9 g) were stirred in dry sulpholan (10 ml) under nitrogen at 90 °C for 3 h. The mixture was diluted with water and extracted with diethyl ether. The extracts were dried (MgSO<sub>4</sub>), the solvent evaporated off and the residue distilled *in vacuo* to give the benzofuran (3) (0.77 g, 73%), b.p. 28—29 °C at 0.05 mmHg, identical (i.r. spectrum) with the material prepared above.

Reactions of Pentafluorophenyl Prop-2-ynyl Ether (1) with Aromatic Hydrocarbons.—(a) With benzene. The ether (1) (3.1 g) and benzene (20 ml) were sealed in a 50-ml tube under reduced pressure (0.05 mmHg) and heated at 140 °C for 116 h. On opening the tube, hydrogen fluoride was evolved. The solvent was evaporated off and the residue was chromatographed on silica (118 × 3.4 cm) (CCl<sub>4</sub> as eluant) to give a crude product (1.08 g, 28%) which after preparative t.1.c. on silica (CCl<sub>4</sub> as eluant) gave 2-benzyl-4,5,6,7-tetrafluorobenzo[b]furan (4), b.p. 103—105 °C at 0.05 mmHg (Found: C, 64.0; H, 2.9. C<sub>15</sub>H<sub>8</sub>F<sub>4</sub>O requires C, 64.3; H, 2.9%);  $M^+$ , 280;  $\delta_{\rm F}$  (CDCl<sub>3</sub>) 148.5, 162.4, 163.4, and 165.4 (upfield from internal CFCl<sub>3</sub>);  $\delta_{\rm H}$  (CDCl<sub>3</sub>)

(b) With p-xylene. The ether (1) (5.65 g) and p-xylene (100 ml) were heated under nitrogen for 118 h during which time HF was evolved. The solvent was distilled in vacuo, the residue was chromatographed on silica ( $114 \times 3.4$  cm) (CCl<sub>4</sub> as eluant) and the enriched product, after preparative

t.l.c. on silica (same solvent), gave 2-(2,5-dimethylbenzyl)-4,5,6,7-tetrafluorobenzo[b]furan (8) (1.68 g, 21%), b.p. 120— 126 °C at 0.05 mmHg (Found: C, 66.1; H, 4.1.  $C_{17}H_{12}$ -F<sub>4</sub>O requires C, 66.2; H, 3.9%);  $M^+$ , 308;  $\delta_F$  (CDCl<sub>3</sub>) 148.3, 162.0, 163.2, and 165.1 (upfield from external CFCl<sub>3</sub>);  $\delta_H$  (CDCl<sub>3</sub>) 2.33 (s, 2 × CH<sub>3</sub>), 4.07 (m, CH<sub>2</sub>), 6.38 (m, vinylic CH), and 7.10 (m, C<sub>6</sub>H<sub>3</sub>).

Reactions of 1,3,4,5,6,7,8-Heptafluoro-2-naphthyl Prop-2ynyl Ether (2) with Aromatic Hydrocarbons.—(a) With benzene. The ether (2) (2.12 g) and benzene (20 ml) were heated together in a sealed tube at 140 °C for 21 h and the crude product (95% pure by <sup>1</sup>H n.m.r.) (1.70 g, 64%) was isolated by chromatography as before. The material was sublimed at 100 °C at 0.05 mmHg and crystallised from ethanol to give 2-benzyl-4,5,6,7,8,9-hexafluoronaphtho[2,1-b]furan (9), m.p. 98.5—100 °C (Found: C, 62.4; H, 2.1. C<sub>19</sub>H<sub>8</sub>F<sub>6</sub>O requires C, 62.3; H, 2.2%); M<sup>+</sup>, 366;  $\delta_{\rm F}$  (CDCl<sub>3</sub>) 146.6—147.4 (br m), 151.9 (m), and 158.8—159.7 (br m) upfield from internal CFCl<sub>3</sub> in the ratio 2:1:3 respectively, peri  $J_{\rm F-F}$  60 Hz;  $\delta_{\rm H}$  (CDCl<sub>3</sub>) 4.21 (s, CH<sub>2</sub>), 6.95 (m, vinylic CH), and 7.34 (C<sub>6</sub>H<sub>5</sub>).

(b) With p-xylene. The ether (2) (2.86 g) and p-xylene (50 ml) were heated under reflux for 20 h and the product was isolated as before by chromatography to give the crude product (90% pure by <sup>1</sup>H n.m.r.) (2.98 g, 73%). Recrystallisation of this material from ethanol gave 2-(2,5-dimethylbenzyl)-4,5,6,7,8,9-hexafluoronaphtho[2,1-b]furan (10), m.p. 116-117 °C (Found: C, 64.0; H, 3.2. C<sub>21</sub>H<sub>12</sub>F<sub>6</sub>O requires C, 64.0; H, 3.0%);  $M^+$ , 394;  $\delta_{\rm F}$  (CDCl<sub>3</sub>) 145.5-146.5 (br m), 151.4 (m), and 158.0-158.9 (br m) (upfield from internal CFCl<sub>3</sub>) in the ratio 2:1:3 respectively, peri  $J_{\rm F-F}$  61 Hz;  $\delta_{\rm H}$  (CDCl<sub>3</sub>) 2.32 (s, 2 × CH<sub>3</sub>), 4.17 (s, CH<sub>2</sub>), 6.83 (m, vinylic CH), and 7.05 (m, C<sub>6</sub>H<sub>3</sub>).

2,3,4,5,6-Pentafluorobenzyl Benzyl Ketone (6).-Bromopentafluorobenzene (26 g) in dry tetrahydrofuran (200 ml) at -70 °C under nitrogen, was treated with n-butyl-lithium in hexane (65 ml; 1.54M) over 30 min at  $\leq -60$  °C. Diethyl ether (100 ml) was added and the mixture was stirred for 4 h at -70 °C. Copper(1) iodide (20 g) was added, and the temperature was maintained at -70 °C for 5 h, after which the solution was warmed to 0-5 °C when benzyl chloromethyl ketone<sup>6</sup> (4.21 g) was added. After stirring for 12 h at 20 °C all the solvents were removed by distillation at 12 mmHg, dry diglyme (80 ml) was added, and the mixture was maintained at 100 °C for 5 h. The mixture was cooled, diluted with diethyl ether (100 ml) and shaken with saturated NH<sub>4</sub>Cl solution. The organic phase was dried (MgSO<sub>4</sub>), the solvents were evaporated off, and the black residue was separated by chromatography on dry silica (120  $\times$  3.5 cm) using CHCl<sub>3</sub> as eluant to give the crude product (1.75 g, 5%). Recrystallisation ( $\times$ 4) from light petroleum (b.p. 60—80 °C) gave the ketone (6) (0.50 g), m.p. 75.5-76.5 °C (Found: C, 59.8; H, 3.1. C<sub>15</sub>H<sub>9</sub>F<sub>5</sub>O requires C, 60.0; H, 3.0%;  $M^+$ , 300).

Reaction of 2,3,4,5,6-Pentafluorobenzyl Benzyl Ketone (6) with Sodium Hydride in Dimethylformamide.—The ketone (6) (0.41 g) was treated with sodium hydride (0.06 g; 80% dispersion in oil) in dimethylformamide (5 ml) for 1 h at reflux temperature. The mixture was cooled, diluted with diethyl ether, and washed with sulphuric acid (2M). The dried (MgSO<sub>4</sub>) ethereal layer was evaporated and the residue after preparative t.l.c. on silica using CCl<sub>4</sub> as solvent, gave 2-benzyl-4,5,6,7-tetrafluorobenzo[b]furan (4) (0.28 g, 73%), identical (i.r. spectrum) with the material prepared from (1) in benzene.

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