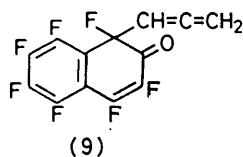
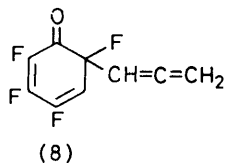
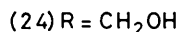
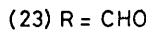
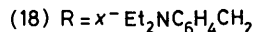
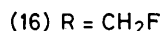
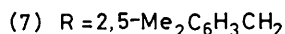
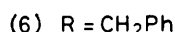
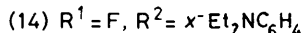
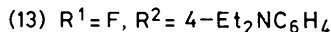
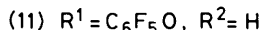
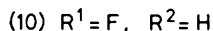
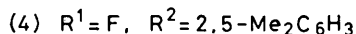
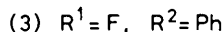
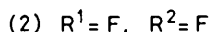
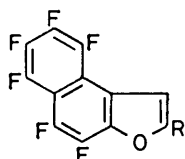
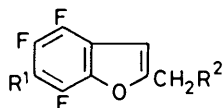
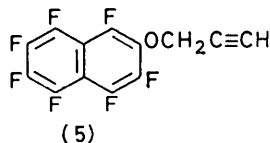
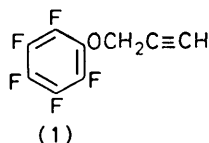


Partially Fluorinated Heterocyclic Compounds. Part 16.¹ Preparation of Furan Derivatives from Pentafluorophenyl and Heptafluoro-2-naphthyl Prop-2-ynyl Ethers with Aromatic Compounds, and the Isolation of Hydrogen-abstraction Products

By Gerald M. Brooke, Chemistry Department, Science Laboratories, South Road, Durham DH1 3LE

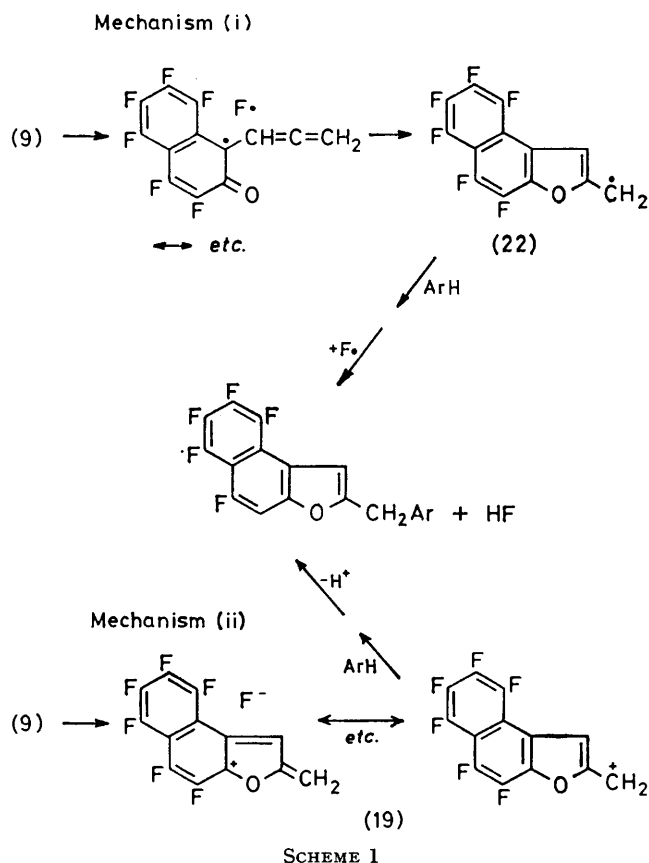
Pentafluorophenyl and heptafluoro-2-naphthyl prop-2-ynyl ethers [(1) and (5)] react in *N,N*-diethylaniline to give among other products 2-methylfuran derivatives [(10) and (11); (15)] formed by hydrogen-abstraction reactions, and 2-(diethylaminobenzyl)furan derivatives [(13) and (14); (17) and (18)]; the 2-fluoromethylfuran (16) is also formed from (5). No aromatic substitution products are obtained from (5) with nitrobenzene or benzyldiyne trifluoride. It was not possible to distinguish between homolytic and heterolytic fission of the aliphatic C-F bonds in the Claisen rearrangement intermediates (8) and (9) involved in these reactions.

In an earlier paper², the flash vapour-phase isomerisation of pentafluorophenyl prop-2-ynyl ether (1) at 370 °C to 2-fluoromethyl-4,5,6,7-tetrafluorobenzofuran (2) was described, together with the reactions of the ether (1) with benzene at 140 °C, and with *p*-xylene at reflux temperature to give the furan derivatives (3) and (4)



respectively. Heptafluoro-2-naphthylprop-2-ynyl ether (5) reacted similarly but more efficiently with benzene and with *p*-xylene to give compounds (6) and (7), respectively.² The formation of all these products was rationalised in terms of two plausible but indistinguishable reaction mechanisms involving the respective

Claisen rearrangement intermediates (8) and (9): (i) a homolytic cleavage of the aliphatic C-F bond, and (ii) a heterolytic cleavage of the C-F bond occurring synchronously with cyclisation. These mechanisms are illustrated in Scheme 1 for compound (9) giving the 2-

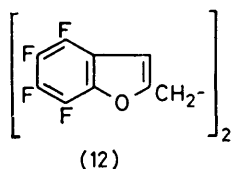


arylmethyl product. Previously substrates having both *ortho*-positions substituted by chlorine or bromine in related aryl prop-2-ynyl ethers when heated in *n*-decane had been shown to give isomeric 2-halogenomethylbenzo-*[b]*furans accompanied by the corresponding 2-methyl derivatives.³ The formation of the hydrogen-abstraction products (the 2-methyl derivatives) in this non-polar solvent was one basis for proposing a radical process.

However, the alternative mechanism involving a cationic intermediate is also plausible for these reactions,* since hydride abstraction from an aliphatic hydrocarbon chain by primary carbocations is a well established process.⁴

The reaction of pentafluorophenyl prop-2-enyl sulphide in refluxing *N,N*-diethylaniline has been shown to give hydrogen-abstraction products amongst others.⁵ We now report the results of a search for hydrogen-abstraction products in reactions involving the ethers (1) and (5) with this solvent and the reaction of (5) in *n*-decane. The reactions of (5) in benzyldiyne trifluoride and nitrobenzene were also investigated, since the orientations of any 2-arylmethylfuran products were expected to distinguish between cationic and radical intermediates.

The reaction of the ether (1) in *N,N*-diethylaniline at 153 °C for 134 h gave a complex mixture of products including large amounts of tar, which was separated initially by treatment with acid into a neutral/acid-containing mixture (*a*) and a nitrogen-base-containing mixture (*b*). The mixture (*a*) contained unchanged ether (1) (2%), pentafluorophenol [10%, based on the consumption of (1) and identified by conversion into the methyl ether with diazomethane], 2-methyl-4,5,6,7-tetrafluorobenzo[*b*]furan (10)⁶ (2%), and 2-methyl-6-pentafluorophenoxy-4,5,7-trifluorobenzo[*b*]furan (11) (2%), presumably formed from (10) and the pentafluorophenoxide ion prevailing in the basic solvent. The orientation of the substituent was assigned by analogy with that of the major isomer formed in the reaction of 4,5,6,7-tetrafluorobenzo[*b*]furan with sodium methoxide.⁷ The mixture (*a*) was also examined carefully for the presence of (12) (synthesised independently from



2-bromomethyl-4,5,6,7-tetrafluorobenzo[*b*]furan⁷ and phenyl-lithium), the potential product of a radical coupling reaction. None was found.

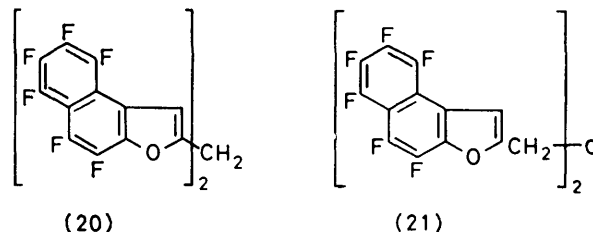
The nitrogen-base-containing mixture (*b*) was exceedingly complex and was mainly tar. However, by a combination of column and thick-layer chromatography, the *para*-substituted *N,N*-diethylaniline derivative (13) (0.2%) and another isomer (14) (0.2%) were isolated. The furan structures of (13) and (14) were assigned on the basis of the n.m.r. absorptions of H-3, which had chemical shifts essentially the same as those of related compounds, and the orientation of the substituted *N,N*-diethylaniline compound (13) was evident from the AA'-BB' character of the absorptions in the aromatic region. The orientation in (14) was not assigned.

The reaction of the naphthyl ether (5) in *N,N*-diethylaniline at 145–147.5 °C over 23 h was more efficient than that of (1), though much tar was again produced, and gave the 2-methyl compound (15) (1%), the 2-

fluoromethyl compound (16) (2%), the *para*-substituted *N,N*-diethylaniline (17) (14%), and an isomer (18) (10%) the orientation of which was not determined. The structures of all these compounds were assigned from their ¹H chemical shifts which were essentially the same as those of related compounds.

The isomerisation of (5) to the 2-fluoromethyl compound (16) is the first example to be reported of a fluorine migration in the liquid phase, and can be rationalised by an extension of either mechanism in Scheme 1. The formation of the 2-methyl derivatives (10) and (11), and (15) from (1) and (5) respectively, demonstrates again the hydrogen atom or hydride ion donating ability of *N,N*-diethylaniline.

The reaction of the naphthyl ether (5) was also carried out under strictly anhydrous conditions in *n*-decane at 150–154 °C over 23 h. The 2-methyl compound (15) was again obtained (1%), accompanied by the naphthalenone (9)¹ (2%), the methane derivative (20)¹ (43%), and the ether (21)¹ (6%). Previously we had shown that the 2-fluoromethyl compound (16) *in water* at 145–156 °C gave the coupling products (20) and (21) amongst others,¹



and rationalised their formation in terms of reactions of the initially formed primary carbocation (19). The formation of (20) and (21) from (5) has a precedent in a reaction carried out in anhydrous CF₂ClCFCl₂.¹

The formation of the hydrogen-abstraction product (15) from (5) in *n*-decane suggests that the reactive intermediate is similar in character to those from chlorine- and bromine-containing substrates.³ In an attempt to distinguish between cationic (19) and radical (22) intermediates in reactions with aromatic compounds, benzyldiyne trifluoride and nitrobenzene were used as solvents for (5) since both were expected to give *meta*-oriented substitution products (albeit more slowly than with benzene) with (19), whereas attack by (22) was expected to give a mixture of three isomers with C₆H₅CF₃, and mainly *ortho*- and *para*-derivatives with C₆H₅NO₂, at rates which would be similar to, and faster than that with benzene, respectively.⁸

The naphthyl ether (5) heated with benzyldiyne trifluoride in a sealed tube at 155 °C for 17 h gave unchanged ether (5) (17%), the methane derivative (20) [5% based on the consumption of (5)], and the ether (21) (4%). When compound (5) was heated with nitrobenzene at 147–153 °C for 18 h a complex mixture was again obtained which contained the naphthalenone (9) (9%), the methane derivative (20) (3%), the ether (21) (6%), and the aldehyde (23) (3%) (recognised from its aldehydic

* We acknowledge this suggestion from a referee

proton signal at δ 9.87), and by its reduction with BH_3 -THF to the known alcohol (24).¹ A careful n.m.r. examination of all the fractions obtained during the separation of the products from both these reactions did not reveal the presence of *any* substituted benzyldiyne trifluoride or nitrobenzene derivatives.

To our knowledge, no Friedel-Crafts alkylations have ever been achieved with either benzyldiyne trifluoride or nitrobenzene, so that the failure to obtain any substitution products with these compounds *could* be taken as negative evidence in favour of the heterolytic mechanism (ii) in Scheme 1. However *no* Friedel-Crafts alkylations *nor* any homolytic aromatic substitution reactions of *N,N*-disubstituted anilines have ever been reported either. Yet compound (5) with the electron-rich ring of $\text{C}_6\text{H}_5\text{NEt}_2$ did give the substituted products (17) and (18), though with a lower overall efficiency (24%) than in the reaction with C_6H_6 (64%). Consequently, the reactions reported in this paper do not permit a distinction between the intervention of radical or cationic intermediates formed by homolytic or heterolytic fission, respectively, of the aliphatic C-F bonds in the Claisen rearrangement intermediates (8) and (9). We now regard our conclusion in favour of the exclusive homolytic fission of the aliphatic C-F bond in the thio-Claisen rearrangement intermediate from $\text{C}_6\text{F}_5\text{SCH}_2\text{CH}=\text{CH}_2$ to have been premature:⁵ both homolytic and heterolytic pathways are plausible.

EXPERIMENTAL

Chemical shifts are downfield from internal Me_4Si (¹H) or upfield from internal CFCl_3 (¹⁹F). Thick-layer chromatography separations were carried out on plates [silica (20 g), 18 × 18 cm]. All descriptions of chromatographic separations follow the sequence in which the components were eluted, starting with the fastest moving component.

Reaction of Pentafluorophenyl Prop-2-ynyl Ether (1) with N,N-Diethylaniline. The ether (1) (29.1 g) and *N,N*-diethylaniline (150 ml) were heated under nitrogen at 153 °C for 134 h. The mixture was diluted with ether and extracted with an excess of dilute sulphuric acid [from sulphuric acid, *d* 1.84 (125 ml)]. The ether solution was dried (MgSO_4) and distilled through a fractionating column (20 × 0.5 in) and the residue was distilled *in vacuo* at room temperature and 0.01 mmHg to give a colourless distillate (i) and a tarry residue (ii). The distillate (i) was extracted with sodium hydroxide (2M); the aqueous extracts were acidified and the solution extracted with ether. Evaporation of the dried (MgSO_4) extracts gave a liquid (2.44 g), shown by i.r. to be phenolic material, which was treated with an excess of diazomethane in ether to give a product identified by ¹⁹F n.m.r. and vapour-phase chromatography as mainly $\text{C}_6\text{F}_5\text{-OCH}_3$ by comparison with authentic material. The neutral ether solution from (i) was dried (MgSO_4), the solvent was removed by fractional distillation, and the residue separated by thick-layer chromatography [light petroleum (b.p. 40–60 °C)] to give three major components: (a) the known 2-methyl-4,5,6,7-tetrafluorobenzo[*b*]furan (10) (0.60 g); (b) unchanged ether (1) (0.67 g); and (c) 2-methyl-6-pentafluorophenoxy-4,5,7-trifluorobenzo[*b*]furan (11) (0.11 g), m.p. 94–95.2 °C [from light petroleum (b.p. 40–60 °C)] (Found: C,

49.0; H, 0.7%; M^+ , 368. $\text{C}_{15}\text{H}_4\text{F}_8\text{O}_2$ requires C, 48.9; H, 1.1%; M , 368); δ_{F} (CDCl_3) 148.3 (m), 156.1 (overlapping m), 156.5 (m), 159.4 (m), 160.9 (m), and 162.3 (overlapping m) (ratios 1 : 2 : 1 : 1 : 1 : 2, respectively); δ_{H} (CDCl_3) 2.47 (s, CH_3) and 6.47 (m, 3-H). Chromatography of the tarry residue (ii) (silica, 3 ft × 1 in; CCl_4) gave more compound (11) (0.33 g).

The acid layer from the original product was treated with an excess of sodium hydroxide and the mixture extracted with ether. The extracts were dried (MgSO_4) and evaporated and the unchanged *N,N*-diethylaniline removed by distillation *in vacuo* at 45 °C and 0.05 mmHg. The tarry residue was separated initially by chromatography (silica, 5 ft × 2.5 in; CHCl_3 - CCl_4 2 : 3 v/v) and then by thick-layer chromatography to give a 2-(*x*-diethylaminobenzyl)-4,5,6,7-tetrafluorobenzo[*b*]furan (14) (0.10 g), an oil (Found: C, 64.8; H, 5.0; N, 3.8%; M^+ , 351. Calc. for $\text{C}_{19}\text{H}_{17}\text{F}_4\text{NO}$: C, 64.9; H, 4.9; N, 4.0%; M , 351); δ_{H} (CDCl_3) (148.6, 162.0, 163.5, and 165.1 (equal intensities); δ_{H} (CDCl_3) 0.93 (t, $2 \times \text{CH}_3$), 2.94 (q, $2 \times \text{CH}_2$), 4.27 (s, CH_2), 6.39 (m, 3-H), and 7.20 (pseudo singlet of an AA'BB' system, C_6H_4); and 2-(4-diethylaminobenzyl)-4,5,6,7-tetrafluorobenzo[*b*]furan (13) (0.092 g) m.p. 57–58.5 °C (from MeOH) (Found: C, 65.2; H, 4.7; N, 3.9%; M^+ , 351. $\text{C}_{19}\text{H}_{17}\text{F}_4\text{NO}$ requires C, 64.9; H, 4.9; N, 4.0%; M , 351); δ_{F} (CDCl_3) 148.4, 161.9, 163.3, and 165.0 (1 : 1 : 1 : 1); δ_{H} (CDCl_3) 1.13 (t, $2 \times \text{CH}_3$), 3.30 (q, $2 \times \text{CH}_2$), 3.92 (s, CH_2), 6.36 (m, 3-H), 6.55 and 7.05 (pseudo doublets, parts of an AA'BB' system 1,4-disubstituted C_6H_4) ($J_{2,3}$ 9 Hz).

Reactions of Heptafluoro-2-naphthyl Prop-2-ynyl Ether (5) with Aromatic Compounds.—(a) *With N,N-diethylaniline.* The ether (5) (3.287 g) and *N,N*-diethylaniline (25 ml) were heated at 145–147.5 °C for 23 h. The mixture was separated as in the previous experiment into a neutral fraction (i) and a nitrogen-base-containing fraction (ii). Fraction (i) was separated by thick-layer chromatography [light petroleum (b.p. 40–60 °C)] into 2-methyl-4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan (15) (0.038 g), m.p. 115.5–116.5 °C [from light petroleum (b.p. 60–80 °C)] (Found: C, 53.7; H, 1.1%; M^+ – 1, 289. $\text{C}_{13}\text{H}_4\text{F}_6\text{O}$ requires C, 53.8; H, 1.4%; M – 1, 289); δ_{F} (CDCl_3) 144.9–146.8 (br, m), 151.6 (m), and 157.1–159.0 (br, m) (2 : 1 : 3); δ_{H} (CDCl_3) 2.57 (s, 2- CH_3) and 6.87 (3-H); and 2-fluoromethyl-4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan (16) (0.058 g), m.p. 68–69° [from light petroleum ether (b.p. 40–60 °C)] (Found: C, 50.7; H, 0.8%; M^+ , 308. $\text{C}_{13}\text{H}_3\text{F}_7\text{O}$ requires C, 50.7; H, 1.0%; M , 308); δ_{F} (CDCl_3) 143.0–145.3 (br, m), 147.0 (m), 154.0–157.7 (br, m), and 206.5 (t) (2 : 1 : 3 : 1); δ_{H} (CDCl_3) 5.46 (d, CH_2F) and 7.36 (m, 3-H) ($J_{\text{gem-F,H}}$ 48 Hz).

The nitrogen-base-containing fraction (ii) was distilled *in vacuo* at 45 °C and 0.05 mmHg to remove unchanged *N,N*-diethylaniline and the tarry residue was separated initially by chromatography (silica 90 × 2.4 cm, CHCl_3 - CCl_4 1 : 2 v/v) and then by thick-layer chromatography to give a 2-(*x*-diethylaminobenzyl)-4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan (18) (0.454 g), b.p. 150–190 °C at 0.01–0.05 mmHg (Found: C, 63.2; H, 4.3; N, 3.5%; M^+ , 437. Calc. for $\text{C}_{23}\text{H}_{17}\text{F}_6\text{NO}$: C, 63.2; H, 3.9; N, 3.2%; M , 437); δ_{F} (CDCl_3) 144.6–146.5 (br, m), 151.3 (m), and 156.9–158.9 (br, m) (2 : 1 : 3); δ_{H} (CDCl_3) 1.00 (t, $2 \times \text{CH}_3$), 3.00 (q, $2 \times \text{CH}_2$), 4.35 (s, CH_2), 6.82 (m, 3-H), and 7.20 (pseudo singlet of an AA'BB' system, C_6H_4); and 2-(4-diethylaminobenzyl)-4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan (17) (0.667 g), m.p. 110–111 °C [from light petroleum (b.p. 60–80 °C)] (Found: C, 63.3; H, 3.9; N, 3.6%; M^+ , 437. $\text{C}_{23}\text{H}_{17}\text{F}_6\text{NO}$

requires C, 63.2; H, 3.9; N, 32.%; M , 437); δ_F ($CDCl_3$) 144.9—146.6 (br, m), 151.4 (m), and 156.9—159.0 (br, m) (2 : 1 : 3); δ_H ($CDCl_3$) 1.13 (t, $2 \times CH_3$), 3.3 (q, $2 \times CH_2$), 4.04 (s, CH_2), 6.83 (m, 3-H), and 6.55 and 7.0 (pseudo doublets, parts of an AA'BB' system, 1,4-disubstituted C_6H_4) ($J_{2,3}$ 8 Hz).

(b) *With benzylidene trifluoride.* The ether (5) (2.923 g) and benzylidene trifluoride (15 ml) were sealed at atmospheric pressure in a Carius tube (8×1 in) and heated at 155 °C for 17 h. The solvent was distilled off, *in vacuo* and the dark residue was separated by chromatography (silica, 90×2.4 cm; $CHCl_3-CCl_4$ 1 : 1 v/v) to give two fractions. Fraction (i) was sublimed at 105 °C and 0.05 mmHg to give unchanged ether (5) (0.497 g), the ether-insoluble residue being bis-(4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan-2-yl)-methane ¹ (20) (0.076 g). Fraction (ii) was separated further by thick-layer chromatography ($CHCl_3-CCl_4$ 3 : 7 v/v) to give bis-(4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan-2-yl-methyl) ether ¹ (21) (0.087 g).

(c) *With nitrobenzene.* The ether (5) (2.826 g) and freshly distilled nitrobenzene (12.5 ml) were heated at 147—153 °C for 18 h. The unchanged nitrobenzene was removed by distillation *in vacuo* at 45 °C and 0.05 mmHg and the residue was separated by chromatography as in the previous experiment to give three fractions. Fraction (i) was sublimed at 85 °C and 0.01 mmHg to give 1,3,4,5,6,7,8-heptafluoro-1-(propa-1,2-dienyl)naphthalen-2(1*H*)-one ¹ (9) (0.267 g) and an ether-insoluble residue, the methane derivative ¹ (20) (0.075 g). Fraction (ii) contained the ether (21) (0.159 g). Fraction (iii) was further separated by thick layer chromatography ($CHCl_3-CCl_4$ 1 : 1 v/v) to give 2-formyl-4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan (23) (0.080 g), m.p. 157.5—158 °C [from light petroleum (b.p. 100—120 °C)] (Found: C, 51.0; H, 0.0%; M^+ , 304. $C_{13}H_2F_6O_2$ requires C, 51.3; H, 0.66%; M , 304); δ_F ($CDCl_3$) 141.5 (m), 143.4 (m), 144.3 (m), 153.8 (m), 155.4 (m), and 156.3 (m) (all of equal intensity); δ_H ($CDCl_3$) 8.05 (m, 3-H) and 9.87 (s, CHO).

Treatment of the aldehyde (23) (0.029 g) with an excess of BH_3-THF gave 4,5,6,7,8,9-hexafluoronaphtho[2,1-*b*]furan-2-ylmethyl alcohol ¹ (24) (0.026 g).

Reaction of Heptafluoro-2-naphthyl Prop-2-ynyl Ether (5) in n-Decane. The ether (5) (1.776 g) was heated in *n*-decane (freshly distilled *in vacuo* from $LiAlH_4$) under nitrogen at 150—154 °C for 23 h in glass apparatus which had been baked at 130 °C and allowed to cool to room tempera-

ture under nitrogen just prior to starting the experiment. The unchanged *n*-decane was distilled from the mixture *in vacuo* at <30 °C and 0.01 mmHg and the residue was sublimed at 70 °C and 0.01 mmHg. The sublimate (0.134 g) was separated by thick-layer chromatography [light petroleum (b.p. 30—40 °C)] to give the 2-methyl compound (15) (0.0167 g) and the naphthalenone ¹ (9) (0.030 g). The non-sublimable residue (1.606 g) was separated by a combination of washing with ether, sublimation *in vacuo* at up to 208 °C and 0.01 mmHg, and thick-layer chromatography ($CHCl_3-CCl_4$ 3 : 7 v/v) into two components: the methane derivative ¹ (20) (0.697 g) and the ether ¹ (21) (0.095 g).

1,2-Bis-(4,5,6,7-tetrafluorobenzo[*b*]furan-2-yl)ethane (12).—This compound was obtained inadvertently as the only product from the reaction of 2-bromomethyl-4,5,6,7-tetrafluorobenzo[*b*]furan ⁷ (1.48 g) with phenyl-lithium in benzene (50 ml; 1*M*), which had been treated with copper(I) bromide (3.85 g) suspended in ether (50 ml). The mixture was heated under reflux for 22 h, then washed with ammonium chloride solution, and the organic phase was separated, dried ($MgSO_4$) and distilled. Recrystallisation of the residue from light petroleum (b.p. 100—120 °C) gave the ethane derivative (12) (0.20 g), m.p. 190—191 °C (Found: C, 53.3; H, 1.1%; M^+ , 406. $C_{18}H_6F_8O_2$ requires C, 53.2; H, 1.5%; M 406); δ_H ($CDCl_3$) 3.23 (s, $2 \times CH_2$) and 6.52 (m, $2 \times 3-H$).

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