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The Radical Addition of Toluene to Fluorocyclobutenes

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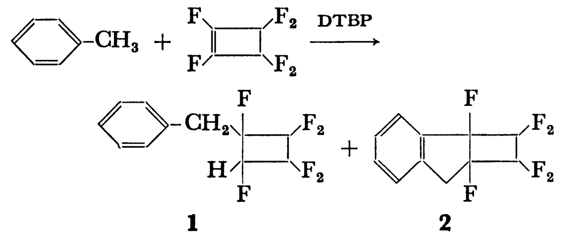
Synopsis. Fluorine-containing cyclobutane derivatives, 1-benzyl-1,2,2,3,3,4,-hexafluorocyclobutane (**1**) and 1,5,6,6,7,7-hexafluorobenzo[2,3]bicyclo[3.2.0]hept-2-ene (**2**), were synthesized in one step by the radical reaction of toluene and hexafluorocyclobutene. On the other hand, a similar reaction of toluene and 1,2-dichlorotetrafluorocyclobutene gave no adduct, but a substituted product, 1-benzyl-2-chlorotetrafluorocyclobutene (**4**).

In earlier papers, the radical addition reactions of such compounds as alcohols, ethers, and aldehydes to hexafluorocyclobutene (HFCB) and 1,2-dichlorotetrafluorocyclobutene (CFCB) have been reported to give the corresponding 1: 1 adducts or their dehydrochlorinated products.[1] However, no investigation is known into the addition of aromatic compounds to these fluorocyclobutenes. In the present work, we carried out a di-*t*-butyl peroxide-induced reaction of toluene to HFCB and CFCB as a part of our synthetic studies of the free-radical addition of aromatic compounds to fluoro olefins.[2,3]

Two different reaction conditions, Methods A and B, were employed. In Method A, excess toluene to fluorocyclic olefins and small amounts of DTBP were used, whereas in Method B, equimolar amounts of toluene and cyclic fluoro olefins were reacted in the presence of large amounts of DTBP in an inert solvent. The conditions employed in Method A had been found suitable for the synthesis of 1: 1 adducts, and those in Method B, for the preparation of cycloadducts.[2]

Addition Reaction of Toluene to Hexafluorocyclobutene.



1 **2**

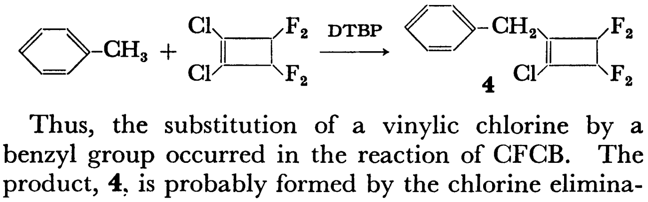
The reaction of toluene and HFCB by Method A afforded 1-benzyl-1,2,2,3,3,4-hexafluorocyclobutane (**1**) as a 1: 1 adduct in a 25.6% yield, together with 1,5,6,6,7,7-hexafluorobenzo[2,3]bicyclo[3.2.0]hept-2-ene (**2**) as a cycloadduct in 1.7% yield. The GLC of **1** indicated the presence of two stereoisomers in the ratio of 86: 14. The mass and IR spectra of these isomers give an almost identical pattern, and the NMR spectra show complex splitting due to H–F and F–F coupling. The assignment of their configurations is made on the basis of the internal chemical shift values between two non-equivalent fluorine atoms of CF$_2$ groups. The signals of the fluorine atoms of the CF$_2$ groups of the predominant isomer appear in the AB quartet (43.1 ppm, 55.3 ppm, $J_{F-F}^{gem}=226$ Hz) and are nearly equivalent as a broad singlet (50.5 ppm). Those of the other isomer appear in two AB quartets (39.4 ppm, 55.6 ppm, $J_{F-F}^{gem}=226$ Hz and 47.4 ppm, 53.4 ppm, $J_{F-F}^{gem}=226$ Hz). The fluorine chemical shifts in the cyclobutane series can be predicted by considering the electric-field effect of the neighboring substituents.[4] Since, in the *cis*-isomer, the electric-field effect of the substituents is additive on the same geminal fluorine nucleus, whereas in the *trans*-isomer this effect is partially compensated for, the *cis*-isomer should show a greater non-equivalence of the fluorine atoms of CF$_2$ groups than does the *trans*-isomer. Therefore, the predominant isomer is estimated to have the *trans*-configuration, in which a hydrogen and a benzyl group are on opposite sides of the plane of the four-membered ring. As will be mentioned later, the configuration of the *trans*-isomer is supported by the NMR spectrum of its oxidized product.

In order to increase the yield of the cycloadduct (**2**), the reaction was carried out by Method B. However, **2** was obtained in only a 4.9% yield, together with **1** (3.9% yield) and large amounts of a high-boiling residue. As compared with Method A, the yield of **1** in Method B decreased markedly, whereas that of **2** increased, though only slightly. The low yield of **2** may be due to the instability of the strained structure with the fused four-, five-, and six-membered ring.

1-Benzyl-2-methylhexafluorocyclobutane (**3**) was obtained as a by-product in a 2.7% yield. The mechanism for the formation of **3** may be explained in terms of the coupling of the benzyl radical and the 2-methyl-1,2,3,3,4,4-hexafluorocyclobutyl radical generated by the addition of a methyl radical to HFCB.

Although a similar reaction of cumene and HFCB was attempted, most of the HFCB was recovered and neither 1: 1 adduct nor cycloadduct was obtained, presumably because of the steric hindrance of methyl groups

Addition Reaction of Toluene to 1,2-Dichlorotetrafluorocyclobutene. The reaction of toluene and CFCB gave benzyl chloride and 1-benzyl-2-chlorotetrafluorocyclobutene (**4**). The corresponding 1: 1 adduct was not obtained. In Method A, the conversion of CFCB was low (14.5%) and the yield based on the amounts of CFCB consumed was 48.4%. In Method B, 28.4% of the CFCB was consumed and **4** was obtained in a 12.1% yield.



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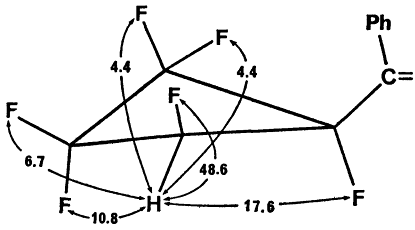
Thus, the substitution of a vinylic chlorine by a benzyl group occurred in the reaction of CFCB. The product, **4**, is probably formed by the chlorine elimination from an intermediate radical generated by the addition of a benzyl radical to CFCB. The different behavior between HFCB and CFCB in the radical reaction with toluene seems to be due mainly to the difference in the carbon-halogen bond dissociation energy. Similar chlorine-substituted products have been reported to be obtained by the radical reaction of alkylbenzenes and chloro olefins.[5]

Oxidation of the Adducts. The methylene groups of **1** and **2** were oxidized to carbonyl groups. The oxidation of **1** by chromium trioxide afforded 1-benzoyl-1,2,2,3,3,4-hexafluorocyclobutane (**5**) in a 72.9% yield. The NMR spectrum of **5** is more simple than that of **1**. The *trans* configuration is also supported by a comparison of the chemical shifts and coupling constants of **5** with those of the 1: 1 adduct which was obtained from the photochemical stereospecific *trans*-addition of trichlorosilane and HFCB.[6] A similar oxidation of **2** also gave 1,5,6,6,7,7-hexafluorobenzo[2,3]bicyclo[3.2.0]hept-2-en-4-one (**6**). An attempt to oxidize **4** was unsuccessful and gave only small amounts of benzoic acid. The oxidation of the double bond took place in the case of **4**.



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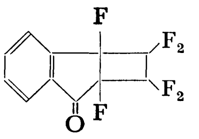

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Experimental

Addition Reaction of Toluene and Hexafluorocyclobutene. Method A: A mixture of toluene (115 g, 1.25 mol), HFCB (53 g, 0.327 mol), and DTBP (7.5 g, 0.051 mol) was heated at 130—140 °C for 24 h. After the recovery of unchanged HFCB (11.4 g; conversion, 78.5%), the liquid product was distilled *in vacuo*. A crude 1: 1 adduct (16.8 g) and a high-boiling residue (6.2 g) were obtained. Three components, two stereoisomers of the 1: 1 adduct and a cycloadduct, were detected by GLC in the ratio of 80.5: 13.0: 6.5. They were separated by preparative GLC.

Trans-1-Benzyl-1,2,2,3,3,4-hexafluorocyclobutane (13.5 g, 20.6% yield): mp 30.8 °C; bp 188 °C; NMR (50% CCl_4 solution) δ 7.14 (5H, s), 3.13 (2H, d-m, 25.2 Hz), 4.92 (1H, d-m, 48.6 Hz), 92.3 (1F, m), 135.8 (1F, d), 43.1 and 55.3 (2F, AB, 226 Hz), 50.5 (2F, broad s); Found: C, 52.01; H, 3.22%. Calcd for $C_{11}H_8F_6$: C, 51.98; H, 3.17%, *cis*-1-benzyl-1,2,2,3,3,4-hexafluorocyclobutane (2.2 g, 3.3% yield): bp 200 °C; n_D^{20} 1.4363; d_4^{20} 1.385; NMR (20% CCl_4 solution) δ 7.1—7.4 (5H, m), 3.11 (2H, d-m, 25.2 Hz), 4.75 (1H, d-m, 50.8 Hz), 110.0 (1F, t-m), 138.8 (1F, d-m), 39.4 and 55.6 (2F, AB, 226 Hz), 47.4 and 53.4 (2F, AB, 226 Hz); Found: C, 52.08; H, 3.07%. Calcd for $C_{11}H_8F_6$: C, 51.98; H, 3.17% and 1,5,6,6,7,7-hexafluorobenzo[2,3]-bicyclo[3.2.0]hept-2-ene (1.1 g, 1.7% yield): bp 199 °C; n_D^{20} 1.4442; d_4^{20} 1.438; NMR (50% CCl_4 solution) δ 7.1—7.5 (4H, m), 3.2—3.7 (2H, AB), 112.3 (1F, m), 97.0 (1F, m), 47.1 and 53.6 (2F, AB, 218 Hz), 40.6 and 52.1 (2F, AB, 226 Hz); Found: C, 52.39; H, 2.68%. Calcd for $C_{11}H_6F_6$: C, 52.40; H, 2.40%.

Method B: A solution of toluene (46.1 g, 0.500 mol), HFCB (80.0 g, 0.494 mol) and DTBP (75 g, 0.513 mol) in 1,1,2-trichlorotrifluoroethane (187 g, 1.00 mol) was heated at temperatures gradually rising from 130 °C to 160 °C for about 6 h. The product was separated by vacuum distillation and preparative GLC to give **1** (4.9 g, 3.9% yield), **2** (6.1 g, 4.9% yield), and 1-benzyl-2-methylhexafluorocyclobutane[7] (3.6 g, 2.7% yield; bp 198—202 °C; n_D^{20} 1.4325; d_4^{20} 1.322; Found: C, 53.83; H, 3.99%. Calcd for $C_{12}H_{10}F_6$: C, 53.74; H, 3.76%), together with a high-boiling residue (57 g).

Addition Reaction of Toluene and 1,2-Dichlorotetrafluorocyclobutene. Method A: By a procedure similar to that described above, the reaction of toluene (115 g, 1.25 mol), CFCB (60.8 g, 0.312 mol), and DTBP (7.5 g, 0.051 mol) gave benzyl chloride (3.6 g), 1-benzyl-2-chlorotetrafluorocyclobutene (5.5 g, 48.4%; bp 209 °C; n_D^{20} 1.4687; d_4^{20} 1.321; IR $\nu_{C=C}$ 1655 cm^{-1}; NMR (50% CCl_4 solution) δ 7.0—7.2 (5H, m), 3.49 (2H, t-m, 2.6 Hz), 36.6 and 37.9 (4F, AA′BB′); Found: C, 52.76; H, 3.25%. Calcd for $C_{11}H_7ClF_4$: C, 52.72; H, 2.82%), and a high-boiling residue (2.3 g).

Method B: By a procedure similar to that described above, the reaction of toluene (46.1 g, 0.500 mol), CFCB (97.5 g, 0.500 mol), and DTBP (75 g, 0.513 mol) in 1,1,2-trichlorotrifluoroethane (187 g, 1.00 mol) gave benzyl chloride (12.7 g), **4** (4.3 g, 12.1% yield), and a high-boiling residue (23.4 g).

Oxidation of the Adducts. 1-Benzoyl-1,2,2,3,3,4-hexafluorocyclobutane (5): To a solution of chromium trioxide (3.0 g, 0.030 mol) in water (5 ml), a solution of **1** (2.6 g, 0.010 mol) in glacial acetic acid (15 ml) was added. The mixture was then refluxed for 16 hr and poured into an ice-cooled aqueous sodium hydrogen sulfite solution. Dichloromethane (100 ml) was then added, and the organic layer separated was washed and dried over magnesium sulfate. The solvent was allowed to evaporate to give an oily residue (2.6 g), which contained **5**, together with small amounts of unchanged **1**. Further purification was done by preparative GLC to give pure **5** (2.0 g, 72.9% yield): bp 215 °C; n_D^{20} 1.4530; d_4^{20} 1.467; IR $\nu_{C=O}$ 1705 cm^{-1}; NMR (50% CCl_4 solution) δ 7.2—7.9 (5H, m), 5.44 (1H, d-m, 48.6 Hz), 85.9 (1F, m), 132.2 (1F, d), 38.1 and 57.5 (2F, AB, 226 Hz), 46.9 (2F, broad s); Found: C, 49.19; H, 2.24%. Calcd for $C_{11}H_6OF_6$: C, 49.27; H, 2.26%.

1,5,6,6,7,7-Hexafluorobenzo[2,3]bicyclo[3.2.0]hept-2-en-4-one (6): By a similar procedure, the oxidation of a mixture (1.3 g) of **1** (40%) and **2** (60%) by chromium trioxide (2.0 g) gave a mixture (1.2 g) of **5** and **6**. They were separated by preparative GLC to give **6**: n_D^{20} 1.4629; IR $\nu_{C=O}$ 1754 cm^{-1}; NMR (5% CCl_4 solution) δ 7.6—8.0 (4H, m), 105.8 (1F, t-d-d), 123.3 (1F, d-d-d-d), 35.5 and 51.3 (2F, AB, 209 Hz), 40.2 and 49.1 (2F, AB, 226 Hz); Found: C, 49.58; H, 1.63%. Calcd for $C_{11}H_4OF_6$: C, 49.64; H, 1.51%.

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7) A mixture of the two stereoisomers in the ratio of 60: 40.