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The chemistry of poly(trifluoromethyl)benzenes. Part II. Reactions of 1,2,3,5-tetrakis(trifluoromethyl)benzene with organolithium compounds

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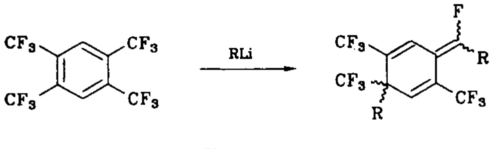
Abstract

1,2,3,5-Tetrakis(trifluoromethyl)benzene reacts with phenyl-lithium or t-butyl-lithium to give mixtures of de-aromatised products, derivatives of 2,5- and 2,4-cyclohexadiene-1-ylidene of molecular composition $C_{10}H_2F_{10}Ph_2$, $C_{10}H_2F_9Ph_3$, $C_{10}H_2F_{10}Bu_2^t$ and $C_{10}H_3F_{10}Bu^t$. The X-ray crystal structure of the triphenyl derivative has been obtained. The ^1H, ^{19}F and ^{13}C NMR data provide a satisfactory proof for the structures of the other compounds.

Introduction

In a preceding paper [1], the reactions of 1,2,4,5-tetrakis(trifluoromethyl)benzene with a number of organolithium reagents have been reported. These reactions proceeded in unusual ways and instead of the expected tetrakis(trifluoromethyl)phenyl-lithium, led to de-aromatised products, i.e. derivatives of 2,5-cyclohexadiene-1-ylidene.



R = n–Bu, tert–Bu, Ph

Recently, we have found that 1,2,3,5-tetrakis(trifluoromethyl)benzene (**1**) displays a similar type of reactivity. The relevant results are described in the present paper.

Results and discussion

As for 1,2,4,5-tetrakis(trifluoromethyl)benzene [1], attempted lithiation of the isomeric compound 1,2,3,5-tetrakis(trifluoromethyl)benzene (**1**) with

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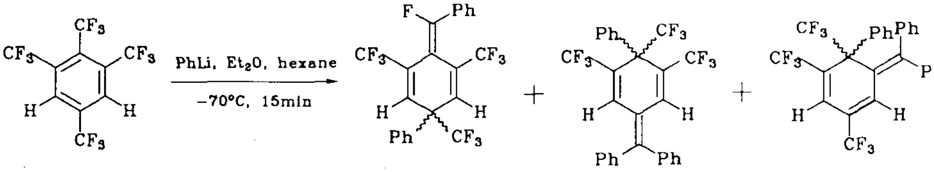
alkyl-lithiums or phenyl-lithium failed. A variety of solvents (diethyl ether, tetrahydrofuran, n-hexane) and reaction temperatures (from −100 °C to 0 °C) were used. In all cases, a vigorous reaction occurred immediately to form deeply coloured solutions, which on addition of heavy water or carbon dioxide produced neither the corresponding deuterium derivative nor carboxylic acid. The reactions were generally conducted in diethyl ether at −70 °C and quenched with acetic acid to give a complex mixture of products; the most abundant components were isolated by column chromatography and identified by spectral methods.

Compound **1**, because of its asymmetric structure, possesses more than one reactive centre and, hence, gives more complex mixtures of products in comparison to those obtained from its symmetric isomer [1]. Thus, the reaction with phenyl-lithium gave three main products **2**, **3** and **4** in a 5:2:1.3 ratio and in about 80% overall yield.



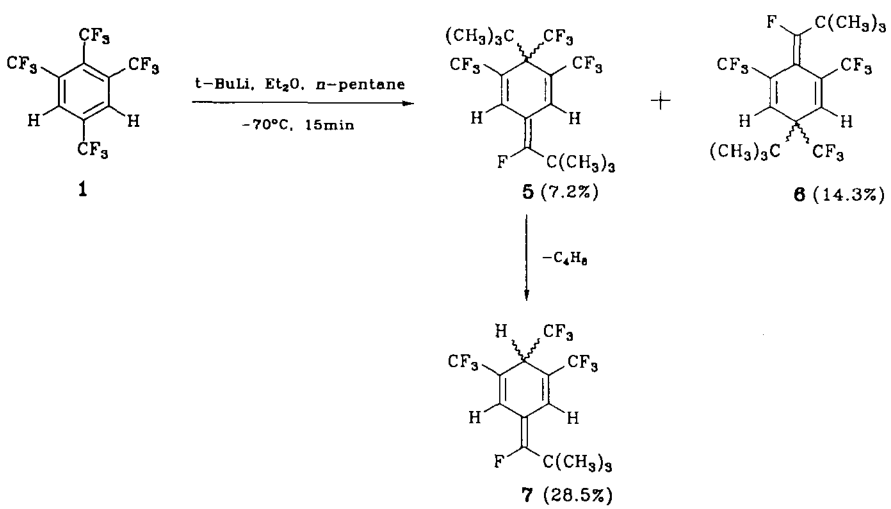
1 2 (50%) 3 (20%) 4 (13%)

The reaction, most probably, involves nucleophilic addition of the phenyl group to one of the aromatic ring carbon atoms bearing a trifluoromethyl group and tele-elimination of a fluoride ion, followed by substitution of the terminal vinylic fluorine [1]. Compound **2** was the most abundant product, suggesting that phenyl-lithium preferentially attacks the least crowded position, i.e. C-5. Attack at the most crowded, but also the most electrophilic, carbon atom, C-2, is less preferred. In this latter case, elimination of fluoride ion occurs either from the opposite or neighbouring trifluoromethyl group, and is followed by substitution of both remaining fluorines by phenyl groups to give two minor products **3** and **4**, respectively.

The reaction of compound **1** with t-butyl-lithium proceeded in a somewhat different manner; compounds **5**, **6** and **7** were formed in a 1:2:4 ratio and were isolated in about 50% overall yield. In this case, however, nucleophilic attack occurred preferentially at carbon atom C-2 to give compound **5** which, because of the enormous steric crowding, underwent transformation into the mono t-butyl derivative **7** by loss of the isobutene molecule. Integrated ^{1}H and ^{19}F NMR spectra have shown that the ration of **5** to **7** changes with time in favour of compound **7**.

Reactions of **1** with n-butyl-lithium and methyl-lithium were also carried out, but they resulted in the formation of very complex mixtures of inseparable products.

Of the products **2**–**7**, only the diphenyl derivatives **3** appeared in a crystalline form; its structure was obtained directly from X-ray analysis (Fig. 1). The atomic coordinates are given in Table 1, and the skeletal bond lengths and bond angles in Tables 2 and 3, respectively. Structures of all



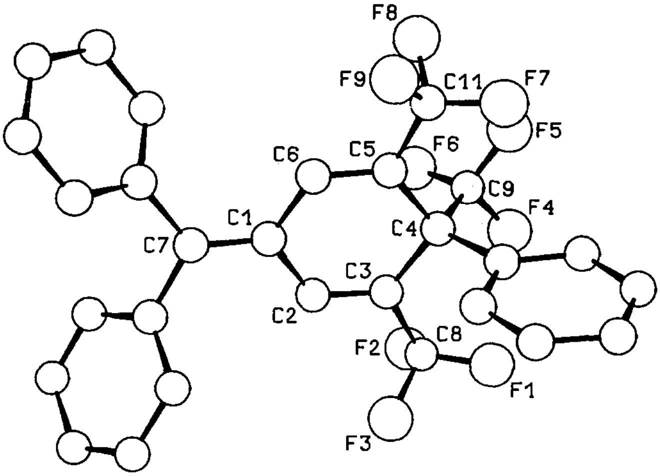


Fig. 1. X-Ray molecular structure of 4,7,7-triphenyl-3,4,5-tris(trifluoromethyl)-2,5-cyclohexadiene-1-ylidene (**3**). Hydrogen atoms and double bonds are not shown.

other new compounds were elucidated from their ^{1}H, ^{19}F (Fig. 2) and ^{13}C NMR (see Experimental) data in conjunction with the crystal structure of compound **3**.

Analysis of the previously reported [1] and the present NMR data for trifluoromethyl-substituted cyclohexadiene-1-ylidenes has shown that signals of the ring protons located between two CF_3 groups characteristically appear at about 6.5 ppm, while those neighbouring only one CF_3 group appear at about 7.5 ppm. A high-field signal (4.20 ppm) in the ^{1}H NMR spectrum of compound **7** indicates that the corresponding proton is bound to an sp^3 carbon atom. The ^{1}H NMR spectra of all the compounds investigated exhibit

TABLE 1

Atomic coordinates for structure **3**

Atom	*x*/*a*	*y*/*b*	*z*/*c*	B_{eq}
F(1)	4840(2)	3623(3)	831(3)	6.5(2)
F(2)	4306(4)	2631(3)	1255(5)	8.6(4)
F(3)	4115(3)	3053(4)	−21(5)	8.7(3)
F(4)	5790(3)	2988(3)	1917(3)	6.9(2)
F(5)	6851(3)	2580(3)	1643(3)	7.3(2)
F(6)	5967(3)	1807(3)	1675(3)	7.2(2)
F(7)	7572(2)	2736(3)	112(3)	6.2(2)
F(8)	7603(3)	1582(4)	462(6)	9.2(3)
F(9)	7578(3)	1886(5)	−862(5)	8.1(5)
C(1)	5453(4)	1282(4)	−708(5)	3.8(3)
C(2)	4989(4)	1826(4)	−277(5)	4.0(3)
C(3)	5216(4)	2414(4)	201(5)	3.8(3)
C(4)	6015(4)	2597(4)	382(4)	4.0(2)
C(5)	6485(4)	2012(4)	−107(5)	3.7(3)
C(6)	6222(5)	1433(4)	−580(5)	4.5(3)
C(7)	5202(4)	719(4)	−1238(4)	3.8(3)
C(8)	4641(5)	2941(5)	589(7)	6.0(4)
C(9)	6170(5)	2489(5)	1401(5)	5.4(3)
C(10)	6193(4)	3398(4)	41(4)	3.6(2)
C(11)	7290(5)	2096(5)	−119(7)	5.8(4)
C(12)	5668(4)	94(4)	−1586(5)	3.8(2)
C(13)	4426(5)	681(4)	−1505(4)	4.0(2)
C(14)	4085(5)	1302(5)	−1896(5)	5.0(3)
C(15)	3362(6)	1252(6)	−2178(5)	6.1(3)
C(16)	2979(5)	598(8)	−2051(6)	6.5(4)
C(17)	3309(6)	−23(6)	−1600(7)	6.6(4)
C(18)	4027(5)	17(5)	−1390(5)	5.1(3)
C(19)	6488(4)	3996(4)	523(5)	5.0(3)
C(20)	6611(5)	4692(5)	116(6)	6.3(3)
C(21)	6441(6)	4822(5)	−755(7)	6.7(4)
C(22)	6170(5)	4233(6)	−1217(6)	6.7(4)
C(23)	6039(4)	3538(4)	−849(5)	5.0(3)
C(24)	6160(5)	−296(4)	−1066(5)	5.4(3)
C(25)	6582(5)	−878(5)	−1402(7)	6.9(3)
C(26)	6501(6)	−1089(5)	−2283(8)	6.9(4)
C(27)	6016(6)	−726(6)	−2799(6)	7.1(4)
C(28)	5590(5)	−139(5)	−2488(5)	5.7(3)

signals corresponding to phenyl and t-butyl groups of the expected intensities. The characteristic feature of the ^{19}F NMR spectra is a long-range coupling (^{5}J=6.1–8.0 Hz) between the neighbouring trifluoromethyl groups in compounds **3**, **4**, **5** and **7**, and between the vinylic fluorine and one of the CF_3 groups (^{5}J=30.5 and 41 Hz) in compounds **2** and **6**. No couplings were observed between vinylic fluorine and the ring protons in compounds **5** and **7**. The ^{13}C NMR spectra of compounds **2**–**7** are fully consistent with the proposed structures.

TABLE 2

Bond lengths for structure **3**

Bond	Distance (Å)	Bond	Distance (Å)
C(8)–F(1)	1.30(1)	C(12)–C(7)	1.49(1)
C(8)–F(2)	1.29(1)	C(13)–C(7)	1.49(1)
C(8)–F(3)	1.35(1)	C(19)–C(10)	1.39(1)
C(9)–F(4)	1.36(1)	C(23)–C(10)	1.39(1)
C(9)–F(5)	1.32(1)	C(24)–C(12)	1.38(1)
C(9)–F(6)	1.32(1)	C(28)–C(12)	1.42(1)
C(11)–F(7)	1.29(1)	C(14)–C(13)	1.39(1)
C(11)–F(8)	1.38(1)	C(18)–C(13)	1.39(1)
C(11)–F(9)	1.29(1)	C(15)–C(14)	1.40(1)
C(2)–C(1)	1.44(1)	C(16)–C(15)	1.36(2)
C(6)–C(1)	1.46(1)	C(17)–C(16)	1.38(2)
C(7)–C(1)	1.35(1)	C(18)–C(17)	1.39(1)
C(3)–C(2)	1.32(1)	C(20)–C(19)	1.38(1)
C(4)–C(3)	1.53(1)	C(21)–C(20)	1.36(1)
C(8)–C(3)	1.52(1)	C(22)–C(21)	1.34(1)
C(5)–C(4)	1.53(1)	C(23)–C(22)	1.36(1)
C(9)–C(4)	1.56(1)	C(25)–C(24)	1.38(1)
C(10)–C(4)	1.53(1)	C(26)–C(25)	1.38(2)
C(6)–C(5)	1.33(1)	C(27)–C(26)	1.34(2)
C(11)–C(5)	1.49(1)	C(28)–C(27)	1.38(1)

Experimental

The ^1H, ^{19}F and ^{13}C NMR spectra were recorded via a Varian 200 Mz spectrometer in $CDCl_3$ solutions; chemical shifts are in ppm from internal TMS for the proton and carbon nuclei (positive downfield) and from internal $CFCl_3$ for the fluorine nuclei (positive upfield).

The X-ray structural analysis of compound **3** was obtained with a Syntex P2_1 diffractometer using graphite-monochromated MoKα radiation (0.71069 Å). The cell constants were obtained from a least-squares refinement on the setting angles of 25 reflections. The data were collected with the $\omega/2\Theta$ scan technique up to $2\Theta_{max} = 50°$.

Crystal data: $C_{28}H_{17}F_9$, M = 524.42, orthorhombic; space group *Pbca*; $a = 18.47(1)$, $b = 17.54(1)$, $c = 14.978(8)$ Å, $V = 4850.2(7)$ Å^3; $Z = 8$; $F(000) = 2128$; $D_x = 1.44$ g cm^{-3}; μ(MoKα) = 0.89 mm^{-1}.

A total of 2709 reflections were collected of which 2047 were unique; 1959 reflections were found to be $I > 2\sigma_I$. Lorentz and polarisation corrections were applied to the data. No absorption correction was applied at the measurement stage.

The phase problem was solved by direct methods [2]. A total of 37 atoms were located in an E-map. Initially, the positional parameters and individual isotropic temperature factors of all non-hydrogen atoms were refined to $R = 0.165$ [3].

TABLE 3

Bond angles for structure **3**

Bonds	Angle (°)	Bonds	Angle (°)
F(1)–C(8)–F(2)	107.8(8)	C(4)–C(5)–C(6)	124.0(7)
F(1)–C(8)–F(3)	105.0(7)	C(4)–C(5)–C(11)	120.3(7)
F(1)–C(8)–C(3)	117.8(7)	C(5)–C(4)–C(9)	106.4(6)
F(2)–C(8)–F(3)	103.9(8)	C(5)–C(4)–C(10)	109.5(6)
F(2)–C(8)–C(3)	111.9(7)	C(9)–C(4)–C(10)	113.4(6)
F(3)–C(8)–C(3)	109.4(8)	C(4)–C(10)–C(19)	127.3(6)
F(4)–C(9)–F(5)	104.9(6)	C(4)–C(10)–C(23)	116.1(6)
F(4)–C(9)–F(6)	105.1(6)	C(6)–C(5)–C(11)	115.6(7)
F(4)–C(9)–C(4)	112.4(7)	C(7)–C(12)–C(24)	123.3(7)
F(5)–C(9)–F(6)	107.2(7)	C(7)–C(12)–C(28)	119.2(7)
F(5)–C(9)–C(4)	115.4(7)	C(12)–C(7)–C(13)	115.4(6)
F(6)–C(9)–C(4)	111.2(6)	C(7)–C(13)–C(14)	121.0(7)
F(7)–C(11)–F(8)	103.4(8)	C(7)–C(13)–C(18)	121.0(7)
F(7)–C(11)–F(9)	108.4(8)	C(10)–C(19)–C(20)	120.2(7)
F(7)–C(11)–C(5)	119.1(7)	C(19)–C(10)–C(23)	116.6(6)
F(8)–C(11)–F(9)	100.7(8)	C(10)–C(23)–C(22)	120.8(7)
F(8)–C(11)–C(5)	110.2(7)	C(12)–C(24)–C(25)	122.2(8)
F(9)–C(11)–C(5)	113.2(8)	C(24)–C(12)–C(28)	117.5(7)
C(1)–C(2)–C(3)	124.9(7)	C(12)–C(28)–C(27)	118.7(8)
C(2)–C(1)–C(6)	113.7(6)	C(13)–C(14)–C(15)	120.7(8)
C(2)–C(1)–C(7)	123.1(7)	C(14)–C(13)–C(18)	118.0(8)
C(1)–C(6)–C(5)	124.4(7)	C(13)–C(18)–C(17)	120.9(8)
C(6)–C(1)–C(7)	123.0(7)	C(14)–C(15)–C(16)	120.3(9)
C(1)–C(7)–C(12)	123.1(7)	C(15)–C(16)–C(17)	119.7(9)
C(1)–C(7)–C(13)	121.4(7)	C(16)–C(17)–C(18)	120.4(9)
C(2)–C(3)–C(4)	124.3(7)	C(19)–C(20)–C(21)	122.2(8)
C(2)–C(3)–C(8)	117.3(7)	C(20)–C(21)–C(22)	116.9(9)
C(3)–C(4)–C(5)	108.7(6)	C(21)–C(22)–C(23)	123.2(9)
C(3)–C(4)–C(9)	108.8(6)	C(24)–C(25)–C(26)	119.1(9)
C(3)–C(4)–C(10)	109.9(6)	C(25)–C(26)–C(27)	119.7(9)
C(4)–C(3)–C(8)	118.4(6)	C(26)–C(27)–C(28)	122.7(9)

The positions of the hydrogen atoms bonded to carbon atoms were generated from assumed geometries and added with isotropic temperature factors to the set of atomic parameters. The refinement of atomic positional and thermal anisotropic parameters (isotropic for H) was performed by the least-squares full-matrix procedure using SHELX-76. The final value of R was 0.0829 unit weight. The highest peak in the final difference map was 0.27 e $Å^{-3}$.

The refined positional parameters for the non-H atoms of **3**, together with their B_{eq} values, are given in Table 1, and bond lengths and bond angles in Tables 2 and 3.

1,2,3,5-Tetrakis(trifluoromethyl)benzene (**1**) was prepared from mesitylene in three steps: trifluoromethylation of mesitylene with a carbon tetrachloride/hydrogen fluoride mixture at 95 °C [4], oxidation of 2,5,6-trimethyl-

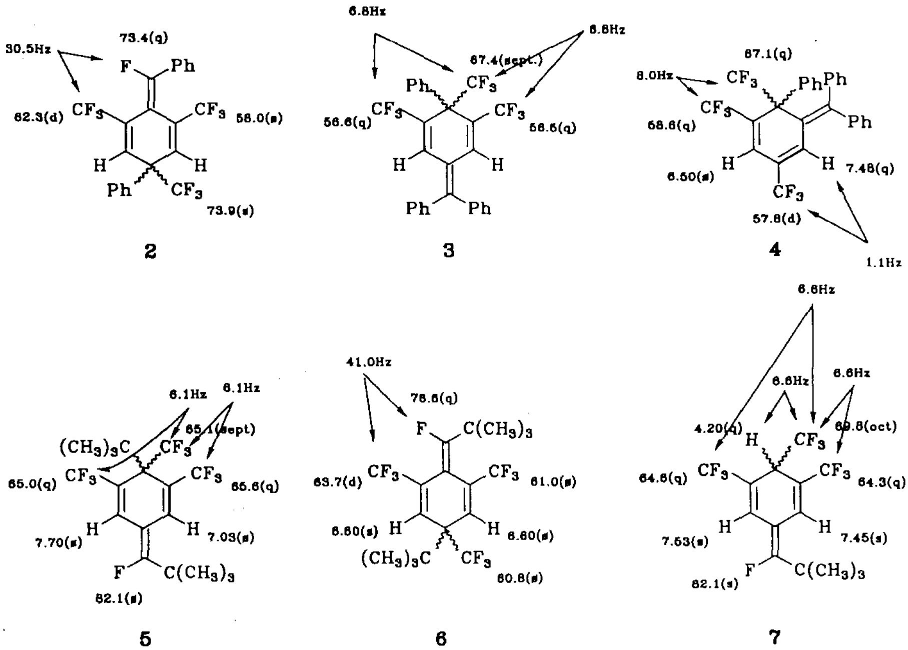


Fig. 2. ^1H and ^{19}F NMR data for compounds **2**–**7**. Chemical shifts are in ppm from internal TMS for the proton nuclei (positive downfield) and from internal $CFCl_3$ for the fluorine nuclei (positive upfield). (The ring proton signals of compounds **2** and **3** overlap with those of the phenyl groups.)

trifluoromethylbenzene with nitric acid at 180 °C followed by refluxing with aqueous potassium permanganate [5] and fluorination of the resultant trifluoromethyltrimesic acid with sulphur tetrafluoride in an excess of hydrogen fluoride at 250 °C for 20 h. Steam distillation and recrystallisation of the crude product from n-pentane gave compound **1** (25% yield) of 99.5% purity (GLC estimate) as white crystals, m.p. 49–50 °C (lit. value [6], m.p. 49.5–50 °C).

Phenyl-lithium was freshly prepared according to a known procedure by refluxing a mixture of benzene, n-butyl-lithium and *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA) in a 4:1:1 molar ratio [7]. t-Butyl-lithium was a commercial 1.4 M solution in n-pentane.

General procedure

All reactions were conducted under an atmosphere of dry argon.

Phenyl-lithium (6 mmol, in a benzene/hexane solution) or t-butyl-lithium (6 mmol, 4.7 ml of a 1.4 M solution in n-pentane) was added with a syringe via a rubber septum to a precooled (−78 °C) stirred solution of 1,2,3,5-tetrakis(trifluoromethyl)benzene (**1**) (1.2 g, 3 mmol) in diethyl ether (20 ml), at such a rate as to keep the temperature below −65 °C. The reactions were highly exothermic. After addition was complete, stirring was maintained at −70 °C for 15 min, and then the reaction was quenched by careful addition of a solution of acetic acid (1 ml) in tetrahydrofuran (3 ml). After warming up to ambient temperature, the solution was poured into water (100 ml) and extracted with diethyl ether (3 × 10 ml). The combined extracts were dried (MgSO$_4$), the solvent was removed under vacuum, and the brownish residue obtained was subjected to chromatographic separation on silica gel (230–400 mesh, 1:100 by weight) using n-hexane as the eluent. ^{1}H and ^{19}F NMR spectra are given in Fig. 2.

7-Fluoro-4,7-diphenyl-2,4,6-tris(trifluoromethyl)-2,5-cyclohexadiene-1-ylidene (**2**): colourless liquid. ^{13}C NMR δ: 160.4 (d, C-7, ^{1}J(C–F) = 271 Hz); 134.9 and 132.8 (m, C-3 and C-5); 128–132 (C-2, C-6 and C-arom.); 122.2 and 125.0 (q, CF$_3$, ^{1}J(C–F) = 268 and 273 Hz); 120.9 (qd, CF$_3$, ^{1}J(C–F) = 275 Hz, ^{4}J(C–F) = 5 Hz); 103.6 (d, C-1, ^{2}J(C–F) = 26.5 Hz); 53.9 (q, C-4, ^{2}J(C–F) = 27.5 Hz) ppm.

4,7,7-Triphenyl-3,4,5-tris(trifluoromethyl)-2,5-cyclohexadiene-1-ylidene (**3**): pale-yellow crystals (from CHCl$_3$), m.p. 145–147 °C (uncorrected, decomp.). ^{13}C NMR δ: 154.7 (s, C-7); 134.5 (q, C-2 and C-6, ^{3}J(C–F) = 5.4 Hz); 139.3 (C-arom.); 127–131 (C-3, C-5 and C-arom.); 124.2 (q, CF$_3$, ^{1}J(C–F) = 235 Hz); 123.2 (q, 2CF$_3$, ^{1}J(C–F) = 275 Hz); 123.9 (s, C-1); 55.8 (q, C-4, ^{2}J(C–F) = 28 Hz) ppm.

6,7,7-Triphenyl-3,5,6-tris(trifluoromethyl)-2,4-cyclohexadiene-1-ylidene (**4**): yellow oil. ^{13}C NMR δ: 153.5 (s, C-7); 141.0 (C-arom.); 138.5 (q, C-2, ^{3}J(C–F) = 6 Hz); 135.2 (q, C-4, ^{3}J(C–F) = 4.2 Hz); 127–131 (C-3, C-5 and C-arom.); 124.2, 123.0 and 122.1 (q, CF$_3$, ^{1}J(C–F) = 283, 275 and 276 Hz); 122.5 (s, C-1); 54.2 (q, C-6, ^{2}J(C–F) = 27.3 Hz) ppm.

7-Fluoro-4,7-bis(t-butyl)-3,4,5-tris(trifluoromethyl)-2,5-cyclohexadiene-1-ylidene (**5**): colourless liquid. ^{13}C NMR δ: 171.0 (d, C-7, ^{1}J(C–F) = 280 Hz); 130.7 and 130.0 (m, C-2 and C-6); 105.1 (d, C-1, ^{2}J(C–F) = 23 Hz); 42.3 (s, *C*(CH$_3$)$_3$); 38.0 (d, *C*(CH$_3$)$_3$, ^{2}J(C–F) = 25 Hz); 29.7 (s, CH$_3$); 28.2 (d, CH$_3$, ^{3}J(C–F) = 4.6 Hz) ppm. Signals for the ring carbons C-3, C-4, C-5 and of the CF$_3$ groups were too weak to be recognised.

7-Fluoro-4,7-bis(t-butyl)-2,4,6-tris(trifluoromethyl)-2,5-cyclohexadiene-1-ylidene (**6**): colourless liquid. ^{13}C NMR δ: 169.9 (d, C-7, ^{1}J(C–F) = 279 Hz); 132.6 and 133.1 (m, C-3 and C-5); 125.7, 123.3 and 121.9 (q, CF$_3$, ^{1}J(C–F) = 272, 273.5 and 276.5 Hz); 105.7 (d, C-1, ^{2}J(C–F) = 24.5 Hz); 56.7 (q, C-4, ^{2}J(C–F) = 24 Hz); 42.9 (s, *C*(CH$_3$)$_3$); 37.6 (d, *C*(CH$_3$)$_3$, ^{2}J(C–F) = 24 Hz; 29.2 (d, CH$_3$, ^{3}J(C–F) = 5.8 Hz); 27.9 (s, CH$_3$) ppm. Signals for the ring carbons C-2 and C-6 were too weak to be recognised.

7-Fluoro-7-(t-butyl)-3,4,5-tris(trifluoromethyl)-2,5-cyclohexadiene-1-ylidene (**7**): colourless liquid. ^{13}C NMR δ: 174.2 (d, C-7, ^{1}J(C–F) = 284 Hz); 130.8 and 130.4 (m, C-2 and C-6); 124.0, 122.5 and 122.4 (q, CF$_3$, ^{1}J(C–F) = 283.8 and 272.2 Hz); 121.3 and 121.2 (q, C-3 and C-5, ^{2}J(C–F) = 32.8 Hz); 109.7 (d, C-1, ^{2}J(C–F) = 22.4 Hz); 39.1 (q, C-4, ^{2}J(C–F) = 32.6 Hz); 37.9 (d, *C*(CH$_3$), ^{2}J(C–F) = 23.0 Hz); 28.7 (d, CH$_3$, ^{3}J(C–F) = 4.6 Hz) ppm.

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