

## Fluorinated Hydroquinones *via* Annulation of Fluorovinylcarbene Complexes with Alkynes<sup>1</sup>

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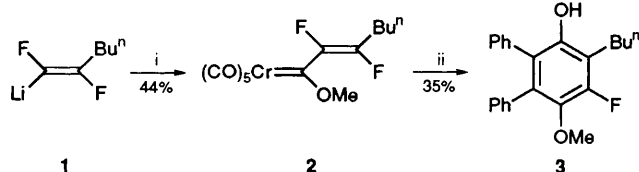
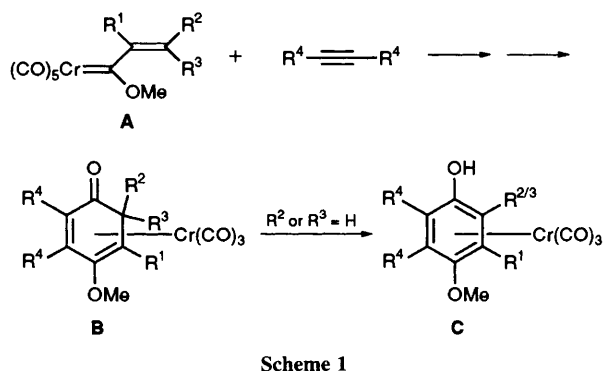
Pentacarbonyl[(*E*)-2,3-difluoro-1-methoxyhept-2-en-1-ylidene]chromium, accessible in few steps from the industrial monomer chlorotrifluoroethene *via* the classical Fischer procedure, reacts with diphenylacetylene to give 2-*n*-butyl-3-fluoro-4-methoxy-5,6-diphenylphenol in an unprecedented tandem carbene annulation–defluorination process.

Fischer-type carbonyl carbene complexes have been established as valuable synthons in organic synthesis based on either metal or ligand centred C–C bond formation.<sup>2</sup> The most valuable reaction so far turned out to be the chromium-mediated carbene annulation, a stepwise formal [3 + 2 + 1] cycloaddition of an  $\alpha,\beta$ -unsaturated carbene ligand, an alkyne

and a carbonyl ligand to form Cr(CO)<sub>3</sub>-coordinated hydroxyarenes.<sup>3</sup> If alkoxy(vinyl)carbene ligands such as in **A** are utilized in this process, generally two different types of products **B** and **C** are to be expected depending on the vinyl substitution pattern (Scheme 1). Given that a  $\beta$ -H substituent is present in the vinyl group a phenol **C** results from a fast tautomerization of the annulation intermediate **B**, whereas the cyclohexadienone usually can be isolated if the  $\beta$ -position is blocked by alkyl groups.<sup>4</sup>

We were interested in applying this strategy to construct fluorinated six-membered ring analogues from hitherto un-

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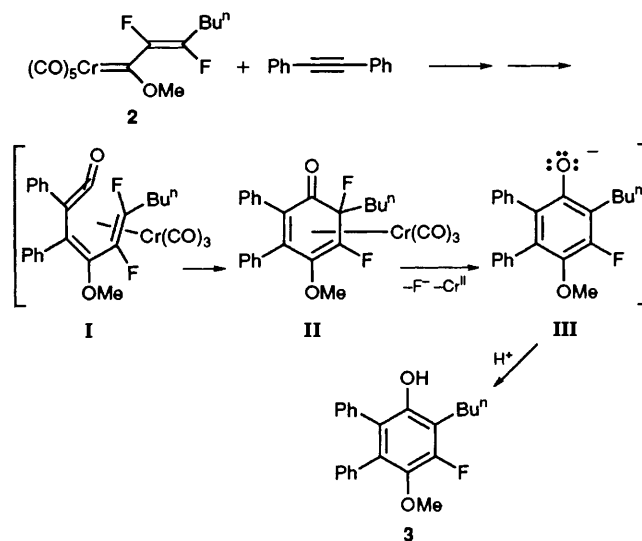
**Scheme 2** Reagents and conditions: i,  $\text{Cr}(\text{CO})_6$ , tetrahydrofuran (THF),  $-30^\circ\text{C}$ , 3 h,  $\text{Me}_3\text{OBF}_4$ ,  $\text{CH}_2\text{Cl}_2$ ; ii,  $\text{PhC}\equiv\text{CPh}$  (1.5 equiv.),  $\text{Bu}^t\text{OMe}$ ,  $55^\circ\text{C}$ , 18 h,  $\text{FeCl}_3$ , dimethylformamide

known fluorovinylcarbene complexes. Whereas the addition of fluorovinylidene complexes to organic electrophiles is well documented,<sup>5-10</sup> the reaction with hexacarbonylchromium as an organometallic electrophile turned out to be very sensitive to the vinyl substitution pattern, in particular to the substituent *trans* to lithium. For instance, (*E*)-1,2-difluorohex-1-enyllithium **1**<sup>6</sup> added smoothly to  $\text{Cr}(\text{CO})_6$  and, after alkylation with  $\text{Me}_3\text{OBF}_4$ , gave carbene complex **2** in moderate yield (Scheme 2), while both trifluorovinylidene and analogues bearing a sterically demanding *trans* substituent ( $\text{Bu}^t$ ,  $\text{SiMe}_3$ ) failed to add under various conditions.

On warming the difluorovinylcarbene complex **2** in  $\text{Bu}^t\text{OMe}$  under reflux in the presence of 1.5 equiv. of diphenylacetylene a carbene annulation occurs and, after oxidation and chromatographic workup, the monofluorohydroquinone monoether **3**<sup>‡</sup> was isolated in moderate yield

<sup>‡</sup> Selected spectroscopic data: **2**, IR ( $\text{Et}_2\text{O}$ ):  $\nu_{\text{CO}}/\text{cm}^{-1}$  2065m, 1985sh and 1959vs;  $^1\text{H}$  NMR (400 MHz,  $\text{CD}_3\text{COCD}_3$ ):  $\delta$  4.89 (s, 3H,  $\text{OCH}_3$ ), 2.53 (ddt, 2H,  $^3J_{\text{HF}}$  23.2,  $^4J_{\text{HF}}$  6.9,  $^3J_{\text{HH}}$  6.9 Hz,  $=\text{CF}-\text{CH}_2$ ), 1.64 (quint., 2H,  $^3J$  7.1 Hz,  $\text{CH}_2-\text{CH}_2-\text{CH}_3$ ), 1.42 (sext., 2H,  $^3J$  7.1 Hz,  $\text{CH}_2-\text{CH}_3$ ) and 0.92 (t, 3H,  $^3J$  7.1 Hz,  $\text{CH}_3$ );  $^{13}\text{C}$  NMR (100.6 MHz,  $\text{CD}_3\text{COCD}_3$ ):  $\delta$  323.7 (d,  $^2J_{\text{CF}}$  60 Hz, C-1), 225.3 ( $\text{CO}_{\text{trans}}$ ), 216.7 (d,  $^4J_{\text{CF}}$  8 Hz,  $\text{CO}_{\text{cis}}$ ), 153.4 (dd,  $^1J_{\text{CF}}$  286,  $^2J_{\text{CF}}$  59 Hz), 154.4 (dd,  $^1J_{\text{CF}}$  209,  $^2J_{\text{CF}}$  33 Hz, C-2, C-3), 68.3 ( $\text{OCH}_3$ ), 28.1 (d,  $^2J_{\text{CF}}$  21 Hz,  $=\text{CF}-\text{CH}_2$ ), 28.0 ( $\text{CH}_2-\text{CH}_2-\text{CH}_3$ ), 22.5 ( $\text{CH}_2-\text{CH}_3$ ) and 13.9 ( $\text{CH}_3$ );  $^{19}\text{F}$  NMR (282 MHz,  $\text{CD}_3\text{COCD}_3$ ,  $\text{CFCl}_3$  ext.):  $\delta$  -109.0 (dt,  $^3J_{\text{FF}}$  116,  $^3J_{\text{FH}}$  23 Hz,  $\text{CH}_2-\text{CF}=\text{C}$ ) and -135.3 (d,  $^2J_{\text{FF}}$  116 Hz,  $\text{CH}_2-\text{CF}=\text{CF}-$ ); MS:  $m/z$  354 ( $\text{M}^+$ , 9.3%).

Compound **3**, IR (film):  $\nu/\text{cm}^{-1}$  3544, 3084, 3055, 3028, 2956, 2932, 2862, 1602, 1459, 1416, 1361, 1302, 1238, 1158, 1109, 1073, 1018, 857, 768 and 701  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.25-7.03 (m, 10H, 2  $\text{C}_6\text{H}_5$ ), 4.95 (d, 1H,  $^5J_{\text{HF}}$  1.7 Hz, OH), 3.55 (d, 3H,  $^5J_{\text{HF}}$  0.5 Hz,  $\text{OCH}_3$ ), 2.76 (dt, 2H,  $^3J$  7.2,  $^4J_{\text{HF}}$  1.7 Hz,  $\text{Ar}-\text{CH}_2-$ ), 1.65 (quint., 2H,  $^3J$  7.5 Hz,  $\text{Ar}-\text{CH}_2-\text{CH}_2-$ ), 1.45 (sext., 2H,  $^3J$  7.2 Hz,  $-\text{CH}_2-\text{CH}_3$ ), 0.98 (t, 3H,  $^3J$  7.2 Hz,  $\text{CH}_3$ );  $^{13}\text{C}$  NMR (100.6 MHz,  $\text{CD}_3\text{COCD}_3$ ):  $\delta$  154.4 (d,  $^1J_{\text{CF}}$  244 Hz, C-3), 147.2 (d,  $^3J_{\text{CF}}$  9.2 Hz, C-1), 138.8 (d,  $^2J_{\text{CF}}$  12.8 Hz, C-4), 133.3 (d,  $^4J_{\text{CF}}$  2.7 Hz, C-5), 122.7 (d,  $^4J_{\text{CF}}$  3.4 Hz, C-6), 117.4 (d,  $^2J_{\text{CF}}$  18.2 Hz, C-2), 135.8 (d,  $^4J_{\text{CF}}$  2.9 Hz, C-1'), 134.6 (C-1''), 131.0, 130.5 (C-3', C-3'', C-5', C-5''), 128.9, 127.3 (C-2', C-2'', C-6', C-6''), 127.4, 126.5 (C-4', C-4''), 61.4 (d,  $^4J_{\text{CF}}$  3.3 Hz,  $\text{OCH}_3$ ), 31.6 ( $\text{Ar}-\text{CH}_2-\text{CH}_2-$ ), 23.1 (d,  $^4J_{\text{CF}}$  3.2 Hz,  $\text{Ar}-\text{CH}_2-$ ), 22.7 ( $-\text{CH}_2-\text{CH}_3$ ), and 13.8 ( $\text{CH}_3$ );  $^{19}\text{F}$  NMR (282 MHz,  $\text{CDCl}_3$ ,  $\text{CFCl}_3$  ext.):  $\delta$  -135.2(s); MS:  $m/z$  350 ( $\text{M}^+$ , 100%).



(Scheme 2). The formation of **3** can be rationalized in terms of the generally accepted mechanism for carbene annulation involving chromium-coordinated dienylketene and cyclohexadienone intermediates **I** and **II** (Scheme 3).<sup>2</sup> We suggest that the striking and unprecedented cleavage of a C-F bond  $\alpha$  to a carbonyl group is facilitated by a redox process generating the phenolate **III** and an uncoordinated  $\text{Cr}^{\text{II}}$ -species. Interestingly and in contrast to the vast majority of chromium-mediated carbene annulation reactions studied in our group, no  $\text{Cr}(\text{CO})_3$  complex of **3** could be detected even under strictly non-oxidative conditions.

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