Unanticipated formation of *ortho*-sulfone substituted phenols by anionic thia-Fries rearrangement of (aryl triflate)tricarbonylchromium complexes†‡

Zhirong Zhao,[a] Josef Messinger,[b] Uwe Schön,[b] Rudolf Wartchow[c] and Holger Butenschön*[a]

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Tricarbonylchromium complexes of aryl triflates undergo base-mediated anionic thia-Fries rearrangements to generate push–pull substituted [*ortho*-hydroxyaryl(trifluoromethylsulfonyl)phenol]tricarbonylchromium complexes under very mild reaction conditions.

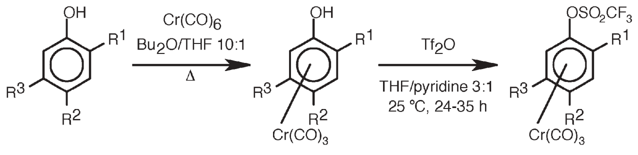
Arynes are not only intriguing and theoretically interesting reactive species,[1–3] but key intermediates for the synthesis of a number of natural and unnatural organic products.[4] Some arynes have been stabilized as ligands in organometallic complexes with the carbon–carbon triple bond being coordinated at the metal.[5,6] Benzyne has been generated from phenyl benzenesulfonate as early as 1976,[7] and more recently aryl triflates have been used to generate arynes by *ortho*-metallation followed by metal triflate elimination.[8] Alternatively, fluoride ion induced displacement of an *ortho*-trimethylsilyl group of an aryl triflate provides a convenient route to benzyne under mild reaction conditions.[9] Suzuki and co-workers reported a high yield synthesis of benzocyclobutenones involving the [2 + 2] cycloaddition of ketene silyl acetals and an aryne generated from *ortho*-haloaryl triflates.[10] A related benzyne furan [2 + 4] cycloaddition approach was used in the synthesis of angucyclines and the first synthesis of the antibiotic C104.[11] (η^6-Aryne)tricarbonylchromium(0) complexes are still unknown, although the benzyne chromium cation has been identified in a mass spectrometric FT-ICR investigation.[12] As there is no obvious reason that (aryne)tricarbonylchromium complexes should not be stable or might at least exist as reactive intermediates we undertook an effort to prepare them by a triflate elimination process, which should, in contrast to most other methods, be compatible with the tricarbonylchromium group. In the context of our interest in (benzocyclobutenone)tricarbonylchromium(0) complexes and related compounds[13–16] we were intrigued by the possibility of preparing these complexes, just as in the uncomplexed case,[10] by a [2 + 2] cycloaddition between an aryne complex and a ketene acetal followed by hydrolysis.

Tricarbonylchromium phenol complexes **1–8** were prepared in up to 90% yield by treatment of the ligands with hexacarbonylchromium in dibutyl ether–THF (10:1) at reflux for 2–3 days. Subsequent treatment with triflic anhydride afforded phenyl triflate complexes **9–16** in up to 88% yield as moderately air stable yellow solids (Table 1). Some phenyl triflate complexes have been prepared earlier by Wulff and co-workers.[17–20]

Next, an *ortho*-deprotonation of the aryl triflate with lithium diisopropylamide or with butyllithium was envisaged in order to induce triflate elimination with formation of the respective aryne complexes. Several reaction conditions including *in situ* quenching with a diene were tested. However, in contrast to our anticipation, no evidence for aryne complex formation was obtained. Instead, high yields of *ortho*-(trifluoromethylsulfonyl)phenol complexes **17–23** were achieved (Table 2). Only entry 6 shows a comparatively poor yield, which is most likely due to the steric congestion in **22** with the trifluoromethylsulfonyl group being located next to the isopropyl substituent. *ortho*-Sulfonylphenols deserve interest in a variety of fields, including the synthesis of pharmacologically important compounds, *e.g.* COX-2-inactivators[25] and combined vasodilator/β-adrenoceptor antagonists,[26] as products of the photolytic acid generation in materials chemistry,[27] in the chemistry of photographical materials,[28] as well as in the structural investigation of phenols with intermolecular hydrogen bonding.[29]

Complexes **17–23** were characterized spectroscopically; crystallization of **17** from hexane–THF (3:1) afforded crystals of its THF monoadduct, which were suitable for an X-ray crystal structure analysis (Fig. 1), confirming the assigned constitution. Presumably due to its push–pull substitution, C2–C3 is shorter than the other

Table 1 (Phenol)- and (phenyl triflate)tricarbonylchromium complexes



1-8 **9-16**

Entry	R^1	R^2	R^3	Product (yield)	Product (yield)
1	H	H	H	**1** (90%)[21–23]	**9** (69%)
2	H	OMe	H	**2** (73%)	**10** (75%)
3	H	Me	H	**3** (65%)[24]	**11** (72%)
4	$SiMe_3$	H	H	**4** (48%)	**12** (39%)
5	OMe	allyl	H	**5** (88%)	**13** (88%)
6	iPr	H	Me	**6** (81%)	**14** (74%)
7	Me	H	iPr	**7** (74%)	**15** (48%)
8	F	H	H	**8** (78%)	**16** (53%)

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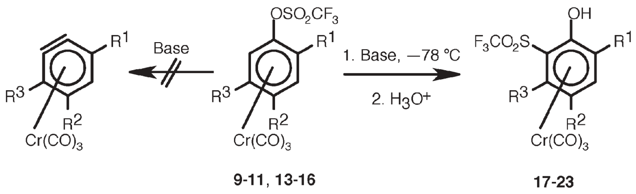
[a] *Institut für Organische Chemie, Universität Hannover, Schneiderberg 1B, D-30167 Hannover, Germany.*
E-mail: holger.butenschoen@mbox.oci.uni-hannover.de
[b] *Solvay Pharmaceuticals Research Laboratories, Hans-Böckler-Allee 20, D-30173 Hannover, Germany*
[c] *Institut für Anorganische Chemie, Callinstraße 9, D-30167 Hannover, Germany*

† Dedicated to Professor Armin de Meijere on the occasion of his retirement.

‡ Electronic supplementary information (ESI) available: Experimental procedures, spectroscopic data of new compounds, and crystallographic details. See DOI: 10.1039/b606092g

Table 2 *ortho*-(Trifluoromethylsulfonyl)phenol complexes from phenyl triflate complexes



Entry	R^1	R^2	R^3	Triflate complex	Product (yield)
1	H	H	H	**9**	**17** (90%)
2	H	OMe	H	**10**	**18** (82%)
3	H	Me	H	**11**	**19** (94%)
4	OMe	allyl	H	**13**	**20** (88%)
5	iPr	H	Me	**14**	**21** (80%)
6	Me	H	iPr	**15**	**22** (47%)
7	F	H	H	**16**	**23** (92%)

C–C bonds of the aromatic ring. Cr–C8 is significantly shorter than Cr–C9 and Cr–C10, indicating substantial back bonding, which most likely is due to a *trans*-effect involving the C1–C2 bond of the aromatic ring.

The formation of *ortho*-(trifluoromethylsulfonyl)phenol complexes is the result of an anionic thia-Fries rearrangement. The preference of this reaction mode is presumably caused by the electron withdrawal of the tricarbonylchromium fragment, which is better satisfied by the formation of the rearranged phenolate than by the alternative formation of an aryne, which is observed with the uncomplexed ligands. The first anionic thia-Fries rearrangement has only recently been reported by Lloyd-Jones, who observed the reaction with some uncomplexed naphthyl or phenyl triflates; in most of the reported cases, however, aryne formation prevailed, and the rearrangement was observed only for some electron poor naphthyl and a few chlorinated phenyl systems.[31] In contrast to these systems removal of the tricarbonylchromium group by established methods[32] in the reactions reported here gives access to the respective donor substituted ligands, some of which are derived from natural products (entries 5–7). Kündig reported an anionic oxa-Fries rearrangement upon treatment of a (phenyl carbamate)tricarbonylchromium complex with butyllithium over 12 h at −20 °C.[33]

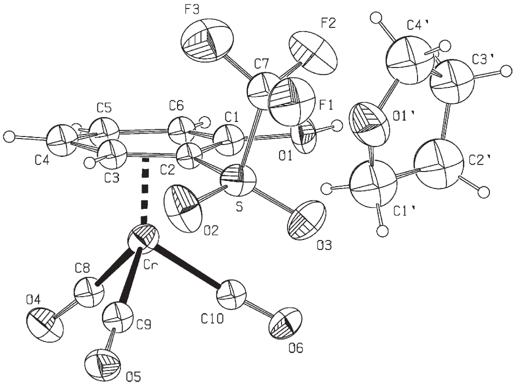
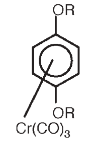


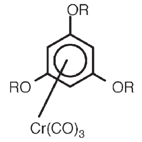
Fig. 1 PLATON plot of **17**·THF. Anisotropic displacement ellipsoids are shown at 20% probability. Only Cr, S, F, O atoms were anisotropically refined.[30] Selected bond lengths [Å] and angles [°]: C1–O1 1.31(1), C1–C2 1.42(2), C1–C6 1.42(1), C2–C3 1.35(1), C3–C4 1.44(1), C4–C5 1.44(2), C5–C6 1.36(2), C2–S 1.79(1), S–C7 1.76(2), Cr–C1 2.29(2), Cr–C2 2.19(1), Cr–C8 1.78(1), Cr–C9 1.88(1), Cr–C10 1.90(2); O1–C1–C2 119(1), C1–C2–S 122(1).

In an alternative approach **12** was treated with tetrabutylammonium fluoride in acetonitrile at 25 °C. Again, an anionic thia-Fries rearrangement occurred instead of benzyne complex formation, giving *ortho*-(trifluoromethylsulfonyl)phenol (**17**) in 86% yield after aqueous work up.

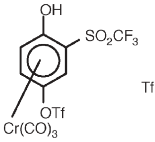
To extend the scope of the reaction the tricarbonylchromium complexes **24** and **25** of hydroquinone[34,35] and of phloroglucinol were prepared in 78% and 67% yield, respectively and triflated to give complexes **26** and **27** in 58% and 35% yield. Treatment of these with butyllithium gave products **28** (78%) and **29** (66%) resulting from single anionic thia-Fries rearrangements.



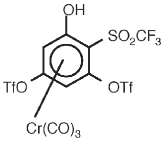
24: R = H (78 %)
26: R = SO_2CF_3 (58 %)



25: R = H (67 %)
27: R = SO_2CF_3 (35 %)



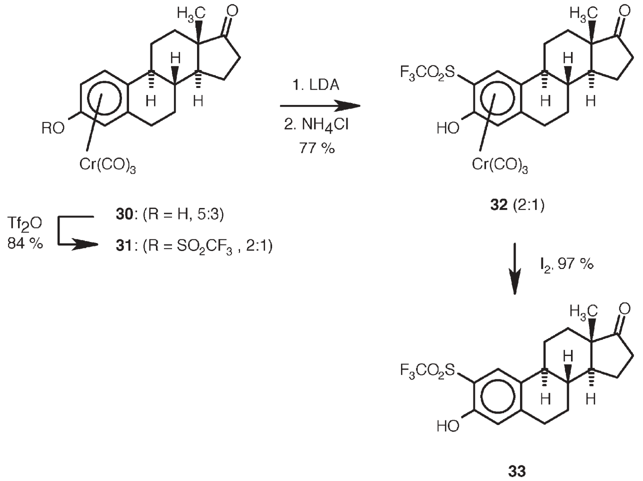
28 (78 %)



29 (66 %)

The bases used so far (LDA, BuLi) cannot differentiate between the enantiotopic *ortho*-hydrogen atoms in the phenyl triflate complex **9**. In order to achieve a desymmetrization resulting in non-racemic **17**, **9** was treated with lithium (*R*,*R*)-di(1-phenylethyl-amide),[36] which has been used by Simpkins for the enantioselective *ortho*-deprotonation of (anisol)tricarbonylchromium.[37–39] Inspection of the NMR spectra (^{1}H, ^{13}C) of the respective Mosher esters revealed that phenol complex **17** had been obtained in only 30% ee.[40] This might be due to a pre-coordination of the chiral base at the Lewis basic oxygen atoms of the triflate group.

The new anionic thia-Fries rearrangement of (phenyl triflate)-tricarbonylchromium complexes was applied to the tricarbonylchromium complex **30** of estrone,[41] which had been obtained as a 5:3 (NMR) mixture of diastereomers. Triflation under standard reaction conditions afforded **31** (2:1) in 84% yield. Subsequent treatment with LDA at −78 °C caused a (presumably for steric reasons) regioselective rearrangement affording **32** exclusively (2:1), which was isolated in 77% yield. Subsequent decomplexation resulted in the new steroid **33** in 97% yield. An alternative approach *via* *ortho*-lithiation leads, after oxidation, to related compounds, however, additional protection and deprotection of the C17 keto function is necessary.[42]



In conclusion we have demonstrated the impressive propensity of (phenyl triflate)tricarbonylchromium complexes to undergo an anionic thia-Fries rearrangement, which takes place at −78 °C in high yield. This pathway contrasts the chemistry of the uncomplexed ligand systems, which usually react with benzyne formation. Thus, the desired (benzyne)tricarbonylchromium complex still remains a highly attractive target of our investigations.

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30 *Crystal data for* **17**·THF: formula $C_{14}H_{13}CrF_3O_7S$, M = 434.30, monoclinic, space group $P2_1/c$, a = 6.519(3), b = 17.392(7), c = 16.169(8) Å, α = 90, β = 101.43(5), γ = 90°, V = 1796.9(14) $Å^3$, Z = 4, μ(Mo-K_α) = 0.815 mm^{-1}, T = 307(2) K, reflections collected/unique 24868/3537, decay correction 46%, $R_{int} = 0.2789$, final R indices $[I > 2\sigma(I)]$ $R_1 = 0.1099$, $wR_2 = 0.1725$, R indices (all data) $R_1 = 0.2711$, $wR_2 = 0.1915$. Only the heavier atoms Cr, S, F, and O were anisotropically refined because of the small amount of observed reflections in the data set. Anisotropic refinement of C atoms is possible in the sense that they do not become non-positive definite, but the direction of longest half axes of the ellipsoids was not reasonable for some atoms. PLATON, an integrated tool for the analysis of the results of a single crystal structure determination (A. L. Spek, *Acta Crystallogr., Sect. A*, 1990, **46**, C34) was used. CCDC 600472. For crystallographic data in CIF or other electronic format see DOI: 10.1039/b606092g.
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