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Communications

The Electron-Deficient Olefin 2,2-Bis(trifluoromethyl)ethylene-1,1-dicarbonitrile: Hydride Abstractions from Allyl and Isobutenyl Ethers and Thioethers[†]

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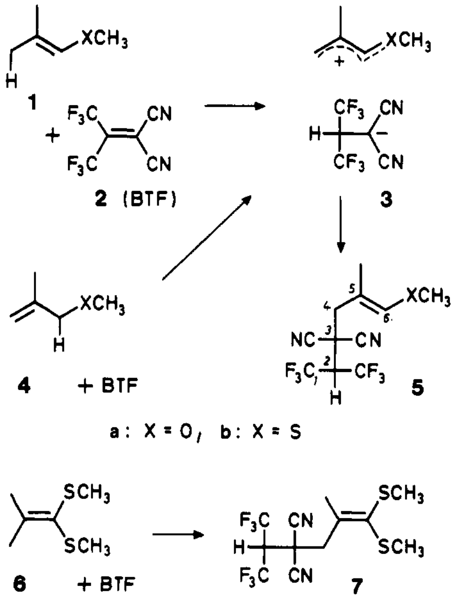
Summary: The title compound (BTF) combines with isobutenyl and methallyl ethers and thioethers furnishing the same formal insertion products 5; an ion pair arising from hydride transfer is proposed as a common intermediate. Allyl ethers (and thioethers) are subject to the same reaction whereas the isomeric propenyl ethers undergo [2 + 2] cycloaddition with BTF. The rate constant for the reaction of ethyl methallyl ether and BTF shows only a modest dependence on solvent polarity.

In the [2 + 2] cycloadditions of 2,2-bis(trifluoromethyl)ethylene-1,1-dicarbonitrile (**2**, BTF)[1] to enol ethers[2] and thioenol ethers,[3] steric effects are more dominant than in cycloadditions of tetracyanoethylene (TCNE).[4,5] Introduction of one β-methyl group into vinyl ether or vinyl sulfide diminished the rate 600- and 7400-fold toward BTF.[3,6] The second β-methyl in isobutenyl methyl ether (**1a**) or sulfide (**1b**) suppressed the [2 + 2] cycloaddition of BTF in favor of a hydride abstraction furnishing the formal insertion products **5** whereas TCNE still afforded the [2 + 2] cycloadducts.[7] It is enlightening that methallyl methyl ether (**4a**) and sulfide (**4b**) combined with BTF giving, once again, adducts **5**. A hydride transfer to BTF producing the allylic ion pair **3** and subsequent ion recombination offer an attractive mechanism. Since nitrile functions stabilize a carbanion better than CF_3 groups, the malononitrile type anion in **3** is the logical precursor of **5**.



The ^{19}F NMR spectra ($CDCl_3$) of **5a,b**[8] show *one* doublet for 2 isochronous CF_3 groups (δ −61.3 or −61.6, $J_{H,F}$ = 7.5 Hz). The 2-H of **5b** (δ 3.72) was resolved as a septet with the same $J_{H,F}$ value, thus excluding a BTF insertion in the opposite direction. *One* doublet of 5-CH_3 (δ 1.82, J_{allyl} = 1.2 Hz) for **5a** (δ 1.95 for **5b**), one vinylic 6-H at 6.21 (6.24), and the 4-H_2 singlet at 2.84 (2.96) establish the anchoring of the BTF residue in accord with **5**. Adducts **5** were isolated by high-vacuum distillation; there was little residue, suggesting that 61–75% (1:1 in CH_2Cl_2, 6 days at room temperature) were conversions rather than yields.

[†] Dedicated to Professor Hans-Jürgen Bestmann, Erlangen, on the occasion of his 65th birthday.

(1) Middleton, W. J. *J. Org. Chem.* **1965**, *30*, 1402.
(2) Huisgen, R.; Brückner, R. *Tetrahedron Lett.* **1990**, *31*, 2553.
(3) Brückner, R.; Huisgen, R. *Tetrahedron Lett.* **1990**, *31*, 2561.
(4) Huisgen, R.; Steiner, G. *Tetrahedron Lett.* **1973**, *14*, 3763.
(5) Graf, H.; Huisgen, R. *J. Org. Chem.* **1979**, *44*, 2594.
(6) Brückner, R.; Huisgen, R. *Tetrahedron Lett.* **1990**, *31*, 2557.
(7) Steiner, G. Ph.D. Thesis, Univ. of Munich, 1972, pp 22, 111; Graf H. Ph.D. Thesis, Univ. of Munich, 1980, pp 30, 192.
(8) Satisfactory elemental analyses and spectra have been obtained for all new compounds.

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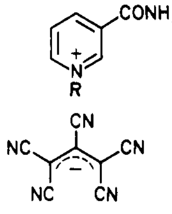
The double bond shift in the formation of **5** from **4** would be consistent with an ene reaction, but the common intermediate **3** on the pathways starting from **1** and **4** appears preferable. The configuration of the double bond in **5** has not been established. The predilection of allylic cations for exo donor substituents suggests *E*. Whereas dimethylketene dimethylacetal still undergoes [2 + 2] cycloaddition with BTF,[2] the slow reaction of the dithioacetal **6** provided the insertion product **7** (70%).

The enzymic redox couple $NAD^+/NADH$ aroused much interest in hydride transfers. N-Substituted 1,4-dihydronicotinamide and an excess of TCNE produced **8**.[9] The pyrylium ion pair **9**, made plausible as an intermediate, belongs to the few examples of hydride abstraction by TCNE.[10] BTF is a superior hydride acceptor. Ion pair **10** (δ_H 3.75, septet, J_{HF} = 8.5 Hz) was ascribed to an "orange oil" obtained from BTF and a 1,2-dihydropyridine derivative;[11] a covalent structure was not excluded and appears preferable.



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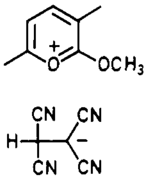

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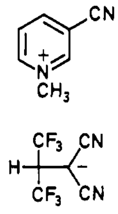

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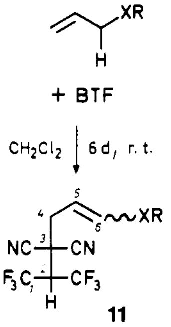
Allyl alkyl ethers and thioethers likewise reacted with BTF at room temperature by hydride transfer. The enol ethers **11a–e**, formal ene products, were isolated as *E*/*Z* mixtures by vacuum distillation. The *Z* content grew with the bulk of *O*-alkyl, reminiscent of the increasing stability of (*Z*)- vs (*E*)-1-alkoxypropenes with bulky OR groups.[12] The thioethers **11f–h** occurred in *E* configuration only.

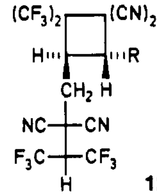


11

11	XR	% Yield	E/Z
a	OCH_3	54	91 : 9
b	OC_2H_5	67	90 : 10
c	$OCH(CH_3)_2$	74	85 : 15
d	$OSi(CH_3)_3$	49	80 : 20
e	$OC(CH_3)_3$	71	57 : 43
f	SCH_3	98	100 : 0
g	SC_2H_5	82	100 : 0
h	$SCH(CH_3)_2$	51	100 : 0

The terminal $CH(CF_3)_2$ in **11** was again established by the ^{19}F doublets of the equivalent CF_3 groups and the 2-H septets (δ 3.68–3.73) with $J_{H,F}$ = 6.9–7.7 Hz; insertion products with $C(CF_3)_2CH(CN)_2$ do not show H,F coupling.[13] Two olefinic H coupled with $J_{5,6}$ = 5.9–7.0 Hz for the *Z* and 12.0–12.5 Hz for the *E* enol ethers **11a–e**; $J_{5,6}$ was 15.0–15.4 Hz for the *E* sulfides **11f–h**.

Do adducts **11** which are still enol ethers and thioethers undergo [2 + 2] cycloadditions with BTF? They do, but they reacted slowly, e.g., 41% **12**, R = *S*-*t*-Bu, from *tert*-butyl vinyl sulfide and 2 equiv of BTF in CH_2Cl_2 after 118 days. The cyclobutanes were crystalline and their structures were confirmed by NMR spectra. Further chemical evidence for **11** came from the conversion of **11a** into the 2,4-dinitrophenylhydrazone **13**.



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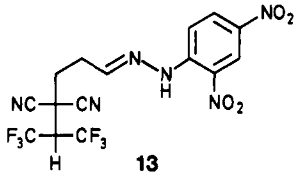
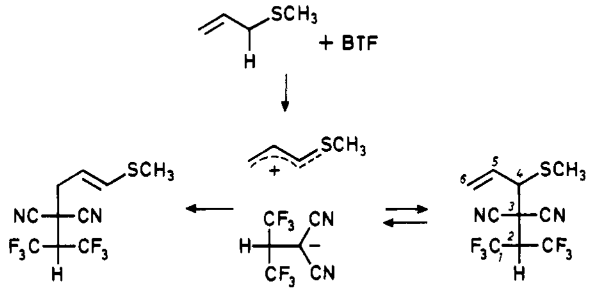


13

Allyl methyl sulfide is stable to TCNE (69 days, room temperature, THF), but reacted smoothly with BTF (→98% **11f**). The reaction drama is more complex. Evaporation of the reactants after *incomplete* conversion revealed up to 40% of **15** besides **11f**. The 200-MHz ^1H NMR spectrum of **15** showed *one* allylic proton at comparatively low field (d, δ 3.80) and three vinyl protons at δ 5.59, 5.70, 6.03 for 6-H_{trans}, 6-H_{cis}, and 5-H; the septet of 2-H (δ 4.25) collapsed to a singlet upon ^{19}F decoupling. We monitored the reaction in the ^1H NMR spectrometer and observed the *concomitant* formation of **15** and **11f** in comparable amounts; within 2 days **15** rearranged to the more stable thioenol ether **11f**.



11f **14** **15**

We regard the ion pair **14** as common precursor; a rearrangement **15** → **11f** by ionization and renewed distribution appears preferable to a 1,3-sigmatropic shift. Divergences of kinetic and thermodynamic control are well documented for reactions of allylic cations with nucleophiles. The formation of ion pair **14** from allyl methyl sulfide → BTF must be irreversible. The return of the hydride to the allylic cation should give rise to allyl methyl sulfide and methyl propenyl sulfide. The latter would be captured by BTF in a [2 + 2] cycloaddition;[2] however, the cyclobutane was not observed here.

Are rate effects consistent with the hydride abstraction mechanism? We have measured spectrophotometrically the rate constants of BTF insertion into ethyl methallyl ether (→ **5a**, C_2H_5 instead of CH_3) in 11 solvents;[14] the k_2 covered a range of 9 and hardly correlated with the empirical parameter E_T of solvent polarity.[15] In contrast, the log k_2 or the [2 + 2] cycloadditions of BTF to donor olefins via 1,4 zwitterions show a high dependence on E_T: k_2 in acetonitrile/k_2 in cyclohexane amounted to 2300 for ethyl *cis*-propenyl ether and to 160 for allyltrimethylsilane.[6]

The assumption that the increase of charge separation in the transition states (TS) of hydride transfer and formation of a 1,4 zwitterion may be similar is ill-considered

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[9] Wallenfels, K.; Bachmann, G.; Diekmann, H.; Friedrich, K.; Hofmann, D.; Kern, R. *Angew. Chem., Int. Ed. Engl.* **1964**, *3*, 241.

[10] Bakker, C. G.; Hazen, C. C. J. M.; Scheeren, J. W.; Nivard, R. J. F. *J. Org. Chem.* **1983**, *48*, 2736.

[11] Gompper, R.; Hultzsch, G.; Ph.D. Thesis G. Hultzsch, Munich 1970, p 33.

[12] Okuyama, T.; Fueno, T.; Furukawa, J. *Tetrahedron* **1969**, *25*, 5409.

[13] Huisgen, R.; Brückner, R. *J. Org. Chem.*, following paper in this issue.

[14] 10^3k_2 (M^{-1} s^{-1}) at 25 °C: cyclohexane 0.48, CCl_4 1.1, benzene 1.3, chlorobenzene 1.6, ethyl acetate 0.58, *o*-dichlorobenzene 4.2, $CHCl_3$ 2.7, CH_2Cl_2 3.1, nitrobenzene 3.3, propionitrile 1.2, acetonitrile 1.8.

[15] Reichardt, C. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 98.

since we are not aware of a model, i.e., the solvent dependence of an authentic hydride shift. The charge distribution pattern is notably different in the two TSs. A radical ion pair generated by SET offers an alternative. However, it would face the same dilemma of solvent dependence; we have no evidence for a chain reaction. Hydrogen atom transfer should furnish a radical pair, but why should that require the strongest donor and acceptor olefins?

In the controversial debate on the NAD^+/NADH mechanism, more authors in recent years preferred the one-step hydride abstraction[16] rather than a multistep SET-initiated pathway. E.g., according to model calculations by MNDO, the TS for a linear hydride shift from 1,4-dihydropyridine to 1,1-dicyanoethylene resembles the ion pair.[17] Our rate study is a painful reminder that a systematic investigation of solvent effects on the rates of hydride transfer reactions is missing. For the time being, we will emphasize by the term "hydride transfer", irrespective of later specification, the relation to NADH reactions.

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(16) Powell, M. F.; Bruice, T. C. *J. Am. Chem. Soc.* **1983**, *105*, 1014.

(17) Verhoeven, J. W.; van Gerresheim, W.; Martens, F. M.; van der Kerk, S. M. *Tetrahedron* **1986**, *42*, 975.

2,2-Bis(trifluoromethyl)ethylene-1,1-dicarbonitrile as a Unique Enophile[†]

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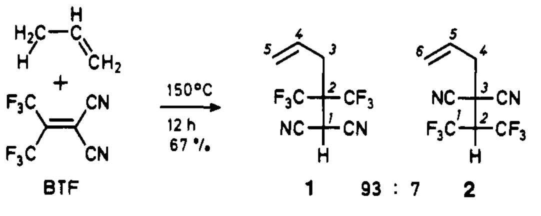
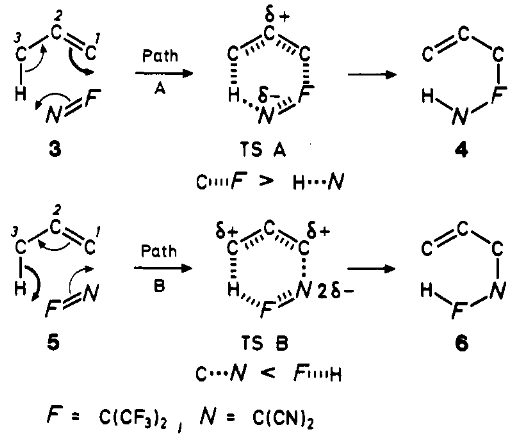
Summary: The title compound (BTF) is the only known electrophilic ethylene derivative which undergoes ene reactions with unactivated alkenes at room temperature. The allylic hydrogen is transferred either to the CF_3- or the CN-bearing carbon of BTF, depending on the structure of the alkene. In a new mechanistic concept, two transition states allow to classify alkenes and to predict the orientation of their ene reactions.

Middleton, the discoverer of the highly electrophilic title olefin (BTF),[1] described its ene reactions with propylene (150 °C, 67% of 1 + 2) and 2,3-dimethyl-2-butene (room temperature, 72%). He noted with unease that a small portion of the first and all of the second alkene gave rise to ene products with $CH(CF_3)_2$ as terminus. This was unanticipated since cyano groups clearly stabilize carbanionic charge better than trifluoromethyl. The clarification required a systematic study.



The uniqueness of BTF as enophile rests on three phenomena: (1) It is the only C=C-based enophile reacting with *common alkenes at room temperature* without Lewis acid catalysis. (2) BTF is an avid hydride-abstracting reagent.[2] (3) Due to different termini of BTF, the ene products reveal the location of partial negative charge in the transition state.

A mechanistic consideration may precede the results. HCC=C is the reacting section of the alkene in 3 and 5, and the two moieties of the BTF molecule are abbreviated by *N* and *F*. The usual enophiles *a*=*b* (maleic anhydride, azodicarboxylic ester, formaldehyde etc.) are *carbophilic*, i.e., the new bond C-*a* is more developed than H-*b* in the transition state (TS). A charge distribution of the pattern of TS A will result. BTF will choose the orientation allowing the cyano groups to stabilize the partial negative charge, and terminal $CH(CN)_2$ will appear in the ene product 4. The interaction of C-1 with the $C(CF_3)_2$ portion of BTF alone would furnish a zwitterion; the simultaneous H transfer diminishes the ionic charges in TS A.



In path B *formal hydride transfer*[3] prevails over C–C bond making; the altered regiochemistry in 5 allows TS B to still profit from the stabilizing effect on the CN groups, but now 6 with terminal $CH(CF_3)_2$ will emerge as the product. Path B does not lead to a full allylic cation,

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[†] Dedicated to Professor Richard Neidlein, Heidelberg, on the occasion of his 60th birthday.

(1) Middleton, W. J. *J. Org. Chem.* **1965**, *30*, 1402.

(2) Brückner, R.; Huisgen, R. *J. Org. Chem.*, preceding paper in this issue.

(3) The term "hydride transfer" is introduced although calculations show that the H migrates with little negative charge. E.g., cyclopropane + cyclopropenium ion: Donkersloot, M. C. A.; Buck, H. M. *J. Am. Chem. Soc.* **1981**, *103*, 6549. 1,4-Dihydropyridine + ethylene-1,1-dicarbonitrile: Verhoeven, J. W.; van Gerresheim, W.; Martens, F. M.; van der Kerk, S. M. *Tetrahedron* **1986**, *42*, 975.

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