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Haloalkynylation of norbornadiene with haloacetylenes activated with a trifluoroacetyl or ethoxalyl group

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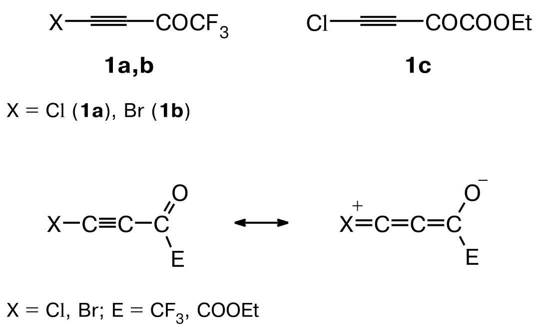
Reactions of norbornadiene with haloacetylenes activated with a trifluoroacetyl or ethoxalyl group proceed as stereospecific conjugated *exo*-addition of the alkynyl substituent and the halogen atom to the double bond of norbornadiene.

Key words: [2+2] cycloaddition, haloalkynylation, electron-withdrawing acetylenes, ynones, norbornadiene.

Norbornadiene is a unique model compound for the study of various cationic rearrangements and addition reactions involving diverse classes of electrophiles.[1] Well-known reactions of norbornadiene with electron-withdrawing olefins and acetylenes follow the 1,3-addition scheme leading to tricyclene structures[2—4] (homodiene synthesis). In the last decade, ruthenium-catalyzed [2+2] cycloaddition of norbornadiene and norbornene to various acetylenes has been under intensive investigation.[5,6] However, although the chemical properties of norbornadiene have been examined in detail for many decades, its reactions with electron-withdrawing haloacetylenes are still represented by a few examples. For instance, prolonged heating with chloropropynonitrile gives a mixture of adducts of [2+2] cycloaddition, homodiene synthesis, and the Wagner—Meerwein rearrangement in low yields.[7] Addition of methyl chloropropynoate catalyzed by ethylaluminum dichloride follows the former two pathways, giving the corresponding products in moderate yields.[8] Recently, we have obtained haloacetylenes **1a—c** activated with a trifluoroacetyl or ethoxalyl group. An unusual feature of these compounds is [2+2] cycloaddition reactions with simple alkenes under mild conditions without irradiation or the use of a catalyst.[9—10] We assumed that these forbidden (by orbital symmetry rules) processes become possible because the electron density distribution in compounds **1a—c** is considerably contributed by a heterocumulene resonance structure, which allows, as in the case of ketenes, reactions with alkenes according to the [$_{\pi}2_s$+$_{\pi}2_a$] cycloaddition mechanism (Scheme 1).

Scheme 1



1a,b **1c**

X = Cl (**1a**), Br (**1b**)

X = Cl, Br; E = CF$_3$, COOEt

It was intriguing to study reactions of acetylenes **1a—c** with norbornadiene because its specific spatial structure substantially hinders the antarafacial arrangement of the reagents that is required for [2+2] cycloaddition and, consequently, the formation of homodiene synthesis products could be expected. We found that reactions of trifluoroacetyl derivatives **1a,b** with norbornadiene occur even at 20 °C, are exothermic, and are completed in 10—12 h. Oxalyl derivative **1c** reacted much more slowly (~5 days). In all three cases, major adducts **2a—c** were obtained in high yields; homodiene synthesis products (15—20%) also detected in the mixture by ^{1}H NMR spectroscopy were not isolated and comprehensively characterized. Structures **2a—c** suggest unusual haloalkynylation with addition of the halogen atom and the terminal C atom of the C≡C bond to the C=C bond of norbornadiene (Scheme 2).

The presence of the C≡C bond and the carbonyl group in compounds **2a—c** are evident from their IR and ^{13}C NMR spectra. The ^{1}H NMR spectra show signals for two protons H—C=C—H at δ 6.10—6.30 with the coupling constant ^3J = 5.7—5.8 Hz and an AB system for the protons C(7)H$_2$ at δ 1.65—1.80 and 2.05—2.20 (^2J = 8.9—9.1 Hz), which is characteristic of substituted norbornenes (see Ref. 11). However, the most interesting problem was to locate the alkynyl substituent and the halogen atom at the C(2) and C(3) atoms of the norbornene framework. The

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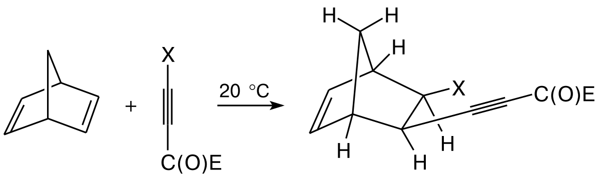
Scheme 2



1a—c

60—80%

2a—c

	a	b	c
X	Cl	Br	Cl
E	CF_3	CF_3	COOEt

signals for the protons H—C(2)—C(3)—H appear at δ 2.90—3.05 and 3.80—4.00 (obviously, the low-field signal refers to the proton H—C—Cl(Br)) with the coupling constant ^3J = 7.3—7.5 Hz. This value correlates well with the coupling constant of the protons H—C(2)—C(3)—H in the *endo*,*endo*-position of the norbornene molecule and is noticeably lower than the coupling constant of the corresponding *exo*,*exo*-protons (common values[12] are 10—11 Hz). It is also known that the mutual coupling constants of the protons H—C(2)—C(3)—H in the *endo*,*exo*-positions of substituted norbornenes never exceed 4.6—4.8 Hz (see Ref. 13). Therefore, both the protons H—C(2)—C(3)—H in compounds **2a—c** have an *endo*-configuration and, consequently, the alkynyl substituent and the halogen atom are in the *exo*-positions. This conclusion is confirmed by the absence of coupling constants for H—C(1)—C(2)—H and H—C(3)—C(4)—H, which is characteristic of the *endo*-protons H—C(2) and H—C(3). In the case of their *exo*-configuration, the corresponding coupling constants are 3.3—3.9 Hz (see Refs 12, 13).

Thus, the reactions of norbornadiene with haloacetylenes **1a—c** occurs as conjugated *exo*,*exo*-addition with an unclear mechanism. It was already mentioned that reactions of norbornadiene with esters and nitrile of chloropropynoic acid do not produce such adducts,[2,8] while acetylenes **1a—c** react with alkenes to give [2+2] cycloadducts.[9,10] In documented reactions of electron-withdrawing haloacetylenes with various nucleophiles[14] (including carbanions[15]), the halogen atom is replaced by a nucleophilic residue. Carbanions are halogenated even with haloacetylenes.[16] However, to our knowledge, haloalkynylation of alkenes has not been described hitherto. It seems to be very unlikely that the reaction involves preliminary heterolytic or homolytic cleavage of the C—Hal bond in compounds **1a—c** followed by polar or radical addition because this would yield a mixture of isomers. We assume that, as in reactions with alkenes, the driving force of the process is an increase in the carbon—halogen bond order and an increase in the positive charge on the latter, which allows an interaction of the highest occupied orbital of the C=C bond of norbornadiene with the lower unoccupied orbital of the C=Cl$^+$ bond of haloacetylene or even with the unoccupied orbital of the chlorine atom. This coordination (Scheme 3) does not demand close approach of the molecules as in an antarafacial interaction of the C≡C bond of haloacetylene with the C=C bond of the bicycle, which is thermodynamically very unfavorable in the case of norbornadiene.[8]

The discovered transformation is of undoubted mechanistic and synthetic interest and deserves further investigations.

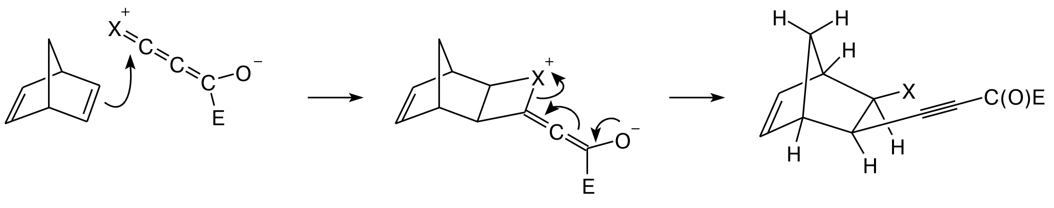
Experimental

Haloacetylenes **1a—c** were prepared by halogenation of appropriate trimethylstannylacetylenes;[9,10] norbornadiene (Lancaster) was used as purchased. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AMX 400 instrument (400 (^{1}H) and 100 MHz (^{13}C)) in $CDCl_3$. IR spectra were recorded on a Bruker IFS 25 instrument (thin films or Nujol).

Synthesis of substituted norbornenes 2a—c (general procedure). Acetylene **1a—c** (0.010 mol) was mixed with norbornadiene (0.014 mol) (the reactions with compounds **1a**,**b** were slightly exothermic). The reaction mixture was kept at 20 °C for 12 (**1a**,**b**) or 120 h (**1c**). The excess norbornadiene was removed *in vacuo* and the residue was separated by column chromatography on silica gel in ethyl acetate—hexane (1 : 20) for **2a**,**b** and ethyl acetate—hexane—chloroform (1 : 20 : 10) for **1c**. After removal of the solvents, adducts **2a,b** were distilled *in vacuo*.

***exo*,*exo*-4-(3-Chlorobicyclo[2.2.1]hept-5-en-2-yl)-1,1,1-trifluorobut-3-yn-2-one (2a).** Yield 1.54 g (62%), b.p. 55 °C (1 Torr). Found (%): C, 53.30; H, 3.28; F, 22.61. $C_{11}H_8ClF_3O$. Calculated (%): C, 53.13; H, 3.25; F, 22.92. IR (ν/cm^{-1}): 1711 (C=O); 2215 (C≡C). ^{1}H NMR, δ: 1.76 (d, 1 H, HC(7),

Scheme 3



X = Cl, Br; E = CF_3, COOEt

J = 9.0 Hz); 2.16 (d, 1 H, HC(7), *J* = 9.0 Hz); 3.01 (d, 1 H, HC(2), *J* = 7.4 Hz); 3.22 (s, 1 H, HC(1)); 3.29 (s, 1 H, HC(4)); 3.96 (dd, 1 H, HC(3), *J* = 7.4 Hz, *J* = 1.3 Hz); 6.19 (dd, 1 H, HC(5), *J* = 5.7 Hz, *J* = 1.3 Hz); 6.28 (dd, 1 H, HC(6), *J* = 5.7 Hz, *J* = 1.3 Hz). ^{13}C NMR, δ: 39.4 (C(7)); 46.9, 49.1 (C(1), C(4)); 50.9 (C(2)); 55.0 (C(3)); 80.6, 105.1 (C≡C); 115.6 (q, CF_3, *J* = 290 Hz); 136.7, 138.5 (CH=CH); 168.8 (q, C=O, *J* = 38 Hz).

***exo*,*exo*-4-(3-Bromobicyclo[2.2.1]hept-5-en-2-yl)-1,1,1-trifluorobut-3-yn-2-one (2b).** Yield 2.02 g (69%), b.p. 66 °C (1 Torr). Found (%): C, 45.33; H, 2.91; F, 19.24. $C_{11}H_8BrF_3O$. Calculated (%): C, 45.07; H, 2.76; F, 19.45. IR (ν/cm^{-1}): 1709 (C=O); 2211 (C≡C). ^{1}H NMR, δ: 1.78 (d, 1 H, HC(7), *J* = 9.0 Hz); 2.11 (d, 1 H, HC(7), *J* = 9.0 Hz); 2.96 (d, 1 H, HC(2), *J* = 7.5 Hz); 3.19 (s, 1 H, HC(1)); 3.22 (s, 1 H, HC(4)); 3.93 (dd, 1 H, HC(3), *J* = 7.5 Hz, *J* = 1.2 Hz); 6.17 (dd, 1 H, HC(5), *J* = 5.8 Hz, *J* = 1.2 Hz); 6.28 (dd, 1 H, HC(6), *J* = 5.8 Hz, *J* = 1.2 Hz). ^{13}C NMR, δ: 37.9 (C(7)); 45.3, 48.8 (C(1), C(4)); 50.3 (C(2)); 52.6 (C(3)); 79.3, 104.5 (C≡C); 114.8 (q, CF_3, *J* = 290 Hz); 136.2, 138.2 (CH=CH); 166.9 (q, C=O, *J* = 38 Hz).

Ethyl *exo*,*exo*-4-(3-chlorobicyclo[2.2.1]hept-5-en-2-yl)-2-oxobut-3-ynoate (2c). Yield 1.92 g (76%). Found (%): C, 61.84; H, 5.27; Cl, 13.92. $C_{13}H_{13}ClO_3$. Calculated (%): C, 61.79; H, 5.19; Cl, 14.03. IR (ν/cm^{-1}): 1671, 1684, 1742 (C=C, C=O); 2212 (C≡C). ^{1}H NMR, δ: 1.33 (t, 3 H, CH_3—, *J* = 7.1 Hz); 1.68 (d, 1 H, HC(7), *J* = 9.5 Hz); 2.05 (d, 1 H, HC(7), *J* = 9.5 Hz); 2.91 (dd, 1 H, HC(2), *J* = 7.3 Hz, *J* = 1.3 Hz); 3.04 (s, 1 H, HC(1)), 3.12 (s, 1 H, HC(4)); 3.89 (dd, 1 H, HC(3), *J* = 7.3 Hz, *J* = 1.3 Hz); 4.30 (q, 2 H, —CH_2—O, *J* = 7.1 Hz); 6.10 (dd, 1 H, HC(5), *J* = 5.6 Hz, *J* = 1.3 Hz); 6.20 (dd, 1 H, HC(6), *J* = 5.6 Hz, *J* = 1.3 Hz). ^{13}C NMR, δ: 14.0 (CH_3); 38.4 (C(7)); 45.1, 49.8 (C(1), C(4)); 52.0 (C(2)); 58.6 (C(3)); 63.2 (CH_2O); 82.8, 100.5 (C≡C); 135.8, 138.8 (CH=CH); 159.0 (COO); 169.7 (C=O).

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