Synthesis of a highly strained permethylenated cycloocta-1,5-diyne derivative by acid-catalysed thermal rearrangement

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Preparation of a dimeric derivative of 1,1,2,2-tetraethynylethane (3,4-diethynylhexa-1,5-diyne) and its unexpected rearrangement to a permethylenated cycloocta-1,5-diyne, the structure of which was confirmed by X-ray crystallography, is reported.

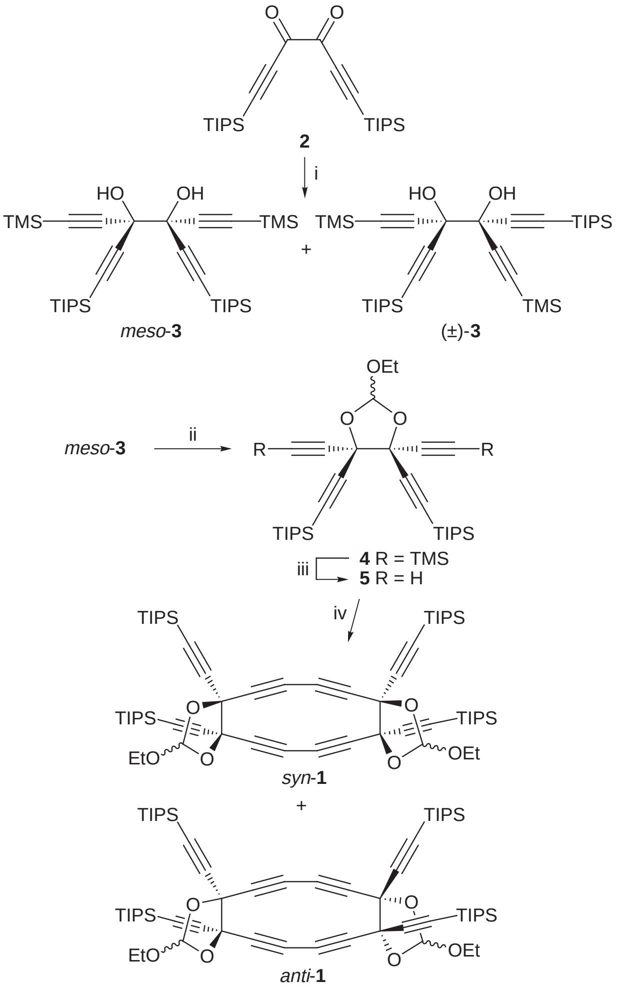
Derivatives of tetraethynylethene (3,4-diethynylhex-3-ene-1,5-diyne) have already been used as building blocks for the preparation of expanded carbon-rich structures.[1] Thus, perethynylated octadehydro[12]annulenes were synthesized by oxidative Hay coupling[2] of *cis*-bis(trialkysilyl)-protected tetraethynylethenes.[3] The same reaction involving their non-planar analogues—derivatives of 1,1,2,2-tetraethynylethane (3,4-diethynylhexa-1,5-diyne)[4,5]—should lead to macrocyclic dimers such as isomeric *syn*-**1** and *anti*-**1**. Here we report the synthesis of these compounds as well as their unexpected, acid-catalysed thermal rearrangement to a permethylenated cycloocta-1,5-diyne, the structure of which was clarified by X-ray crystal structure analysis.

Starting from hexa-1,5-diyne-3,4-dione **2**,[6] the orthoesters **4** and **5** were prepared *via* the diol *meso*-**3** and isolated, in both cases, as an inseparable mixture of diastereoisomers. Subsequent oxidative dimerisation of **5** under Hay conditions gave diastereoisomeric mixtures of *syn*-**1** and *anti*-**1**, which could be separated from each other by column chromatography (Scheme 1). The *syn*-structure with the larger molecular dipole moment was assigned to the product with the longer retention time.

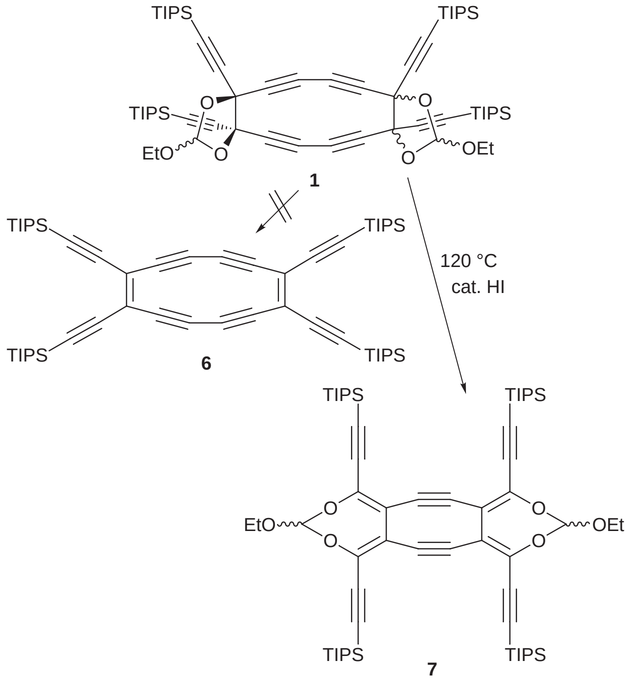
Both *syn*-**1** and *anti*-**1** seemed to be promising precursors to octadehydro[12]annulene **6** (Scheme 2), an interesting, hitherto scarcely available perethynylated antiaromatic annulene.[3] The essential elimination of the orthoester functionality[7] in *syn*-**1** or *anti*-**1**, however, could not be accomplished using the methods developed in our group for the conversion of orthoester derivatives of 1,1,2,2-tetraethynylethanes, such as **4**, into the corresponding tetraethynylethenes. Owing to the instability of *syn*-**1** and *anti*-**1**, both vacuum pyrolysis in the presence of camphorsulfonic acid at 150 °C[5] or heating in 1,2-dichlorobenzene to 170 °C in the presence of catalytic amounts of hydroiodic acid[8] failed to produce **6**. Instead, the latter reaction conditions produced at 120 °C, to our great surprise, exclusively the rearranged product **7**, which was isolated in 41% yield as an inseparable 2 : 1 mixture of diastereoisomers (NMR) featuring unexpectedly high kinetic and thermal stability (Scheme 2).‡

The structure of **7** as a highly strained permethylenated cycloocta-1,5-diyne could only be elucidated by X-ray analysis (Fig. 1).§ The cycloocta-1,5-diyne unit bearing four exocyclic double bonds is nearly planar; the C-atoms $CH(OR)_3$ of the two orthoester moieties are approximately 0.7 Å out of the plane. Two diastereoisomers of **7** were isolated from the acid-catalysed thermolysis, owing to the undefined configuration of these two C-atoms. The analysed crystal, however, contained only one diastereoisomer bearing an *anti* arrangement of the ethoxy groups. In the eight-membered ring, the transannular distance between the triple bonds is 2.59 Å, which is in good agreement with similar cycloocta-1,5-diyne derivatives.[9] The internal bond angles at the sp C-atoms (157.4°) differ considerably from the regular geometry. Furthermore, slight bending of the Pr^i_3Si groups at the sp centres is observed. This is probably a result of crystal packing effects.

The formation of **7** from **1** can be rationalised by assuming a cascade mechanism consisting of electrocyclic or radical reactions. In the first step, thermal cleavage of the C–C bonds in both dioxolane rings occurs by a conrotatory 12π-electrocyclic ring opening. The presence of HI is clearly important for this process since heating **1** in the absence of the acid catalyst only led to extensive decomposition. The formed intermediate contains two parallel-facing hexa-1,2,3,4,5-pentaene moieties. A formal intramolecular [4π + 4π]-cycloaddition between the central butatriene units finally results in the formation of the strained cycloocta-1,5-diyne system. The parent cycloocta-1,5-diyne system has also been obtained, but in poor yield only



Scheme 1 *Reagents and conditions*: i, $Me_3Si–C{\equiv}C–MgBr$, THF, 20 °C, 48% (*meso*-**3**), 25% [(±)-**3**]; ii, $HC(OEt)_3$, CSA (cat.), CH_2Cl_2, 20 °C, 89%; iii, K_2CO_3, MeOH–THF, 95%; iv, CuCl, TMEDA, O_2, CH_2Cl_2, 20 °C, 27% (*syn*-**1**), 44% (*anti*-**1**)



Scheme 2

(2%), by the dimerisation of buta-1,2,3-triene.[9] In both cases, this dimerisation is probably not concerted, but proceeds *via* a biradical mechanism. The higher yield in our system can be explained by the intramolecularity of the reaction in addition to the steric hindrance of the TIPS groups, which precludes intermolecular reactions.

The substitution of the orthoester groups in **1** by other thermally or photochemically removable protecting groups is now under way in order to prepare **6**. Furthermore, experiments with such compounds could clarify the mechanism of the acid required for the formation of **7**.

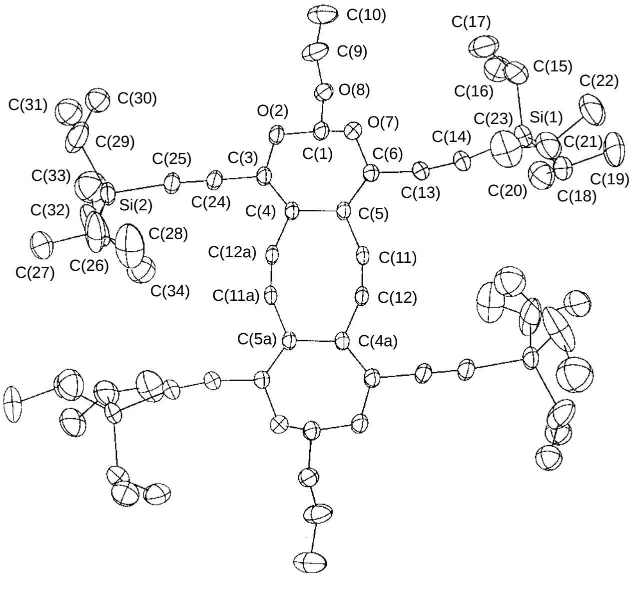


Fig. 1 Molecular structure of **7** in the crystal. The thermal ellipsoids are drawn at the 30% probability level. Selected bond lengths [Å] and angles [°]: C(1)–O(2) 1.420(3), C(1)–O(7) 1.408(3), C(6)–O(7) 1.377(3), C(5)–C(6) 1.353(4), C(4)–C(5) 1.502(3), C(5)–C(11) 1.423(3), C(11)–C(12) 1.206(4), C(6)–C(13) 1.419(3), O(8)–C(1)–O(7) 109.0(2), C(6)–O(7)–C(1) 116.1(2), C(5)–C(6)–C(7) 122.7(2), C(4)–C(5)–C(11) 112.9(2), C(4)–C(5)–C(6) 124.9(2), C(5)–C(11)–C(12) 156.3(2), C(11)–C(12)–C(4a) 158.6(2).

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Notes and References

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‡ *Selected data* for **7** (2 : 1 mixture of diastereoisomers): mp 188–191 °C (decomp.) [Found: C, 70.71; H, 9.49. Calc. For $C_{62}H_{96}O_6Si_4$ (1049.79): C, 70.94; H, 9.22]; λ_{max} ($CHCl_3$)/nm 321 (ε 61 100, sh), 337 (90 100), 351 (88 100), 400 (7500) and 432 (5500); ν($CHCl_3$)/cm^{-1} 2944 (s), 2856 (s), 2122 (w), 1550 (m), 1456 (m), 1217 (s), 878 (m), 722 (s) and 678 (s); δ_H(400 MHz, $CDCl_3$) [5.86 (1.33 H, s), 5.84 (0.67 H, s)], 3.85 (4 H, q, *J* 7.1), 1.30 (6 H, t, *J* 7.1) and 1.10 (84 H, s); δ_C(100.6 MHz, $CDCl_3$) [136.08 major, 135.86 minor (C = *C*–O)], [112.60 major, 112.53 minor (*C* = C–O)], [111.92 minor, 111.43 major (C≡C)], [107.53 minor, 107.43 major (CH, orthoester)], [102.88 major, 102.61 minor (C≡C)], 101.12 (C≡C), [62.76 major, 62.72 minor (CH_2, orthoester)], 18.67 (CH_3, Pr^i) 14.79 (CH_3, orthoester) and 11.29 (CH, Pr^i); *m/z* (MALDI-TOF-MS) 1049 (M^+, 100%).

§ *Crystal data* for **7**: $C_{62}H_{96}O_6Si_4$, M_r = 1049.75, triclinic, space group $P\bar{1}$, D_c = 1.07 g cm^{-3}, Z = 1, a = 9.374(1), b = 11.402(3), c = 15.399(4) Å, α = 97.42(2), β = 92.19(2), γ = 95.00(2)°, V = 1623.8(6) Å^3, T = 223 K, Nonius CAD4 diffractometer, λ(CuKα) = 1.5418 Å. Single crystals were obtained by slow diffusion of pentane into a $CHCl_3$ solution. The structure was solved by direct methods (SHELXS-86: E. Egert and G. M. Sheldrick, University of Göttingen) and refined by full-matrix least-squares analysis (SHELXL-93: G. M. Sheldrick, University of Göttingen), using an isotropic extinction correction and $w = 1/[\sigma^2(F_o^2) + (0.1648P)^2 + 0.84P]$, where $P = (F_o^2 + 2F_o^2)/3$. The Pr^i_3Si groups are statically disordered; for C(16), C(17), C(22) and C(23) two sets of atomic parameters were refined isotropically with weights of 0.7 and 0.3 respectively; for C(30), C(31), C(33) and C(34) three sets of atomic parameters were refined with weights of 0.33. All other heavy atoms were refined anisotropically (H-atoms of the ordered skeleton isotropically, whereby H-positions are based on stereochemical considerations). Final $R(F)$ = 0.070, $wR(F^2)$ = 0.218 for 411 variables and 4514 reflections with $I > 2\sigma(I)$ and $\theta < 65°$. For clarity, only one orientation of the disordered Pr^i_3Si groups is shown in Fig. 1. CCDC 182/874.

1 F. Diederich, *Nature*, 1994, **369**, 199; F. Diederich, in *Modern Acetylene Chemistry*, eds. P. J. Stang and F. Diederich, VCH, Weinheim, 1995, p. 443; R. R. Tykwinski and F. Diederich, *Liebigs Ann./Recueil*, 1997, 649.

2 A. S. Hay, *J. Org. Chem*., 1962, **27**, 3320.

3 J. Anthony, C. B. Knobler and F. Diederich, *Angew. Chem., Int. Ed. Engl*., 1993, **32**, 406; J. Anthony, A. M. Boldi, C. Boudon, J.-P. Gisselbrecht, M. Gross, P. Seiler, C. B. Knobler and F. Diederich, *Helv. Chim. Acta*, 1995, **78**, 797.

4 A. H. Alberts and H. Wynberg, *J. Chem. Soc., Chem. Commun*., 1988, 748; H. Hauptmann, *Angew. Chem., Int. Ed. Engl*., 1975, **14**, 498; H. Hauptmann, *Tetrahedron Lett*., 1975, 1931; H. Hauptmann, *Tetrahedron Lett*., 1974, 3587; K. G. Migliorese, Y. Tanaka and S. I. Miller, *J. Org. Chem*., 1974, **39**, 739; K. Sisido, N. Hirowatari, H. Tamura, H. Kobata, H. Takagisi and T. Isida, *J. Org. Chem*., 1970, 35, 350; F. J. Wilson and W. M. Hyslop, *J. Chem. Soc*., 1924, 1556.

5 R. R. Tykwinski, F. Diederich, V. Gramlich and P. Seiler, *Helv. Chim. Acta*, 1996, **79**, 634.

6 R. Faust and C. Weber, *Tetrahedron*, 1997, **53**, 14 655.

7 A. P. Marchand, V. Vidyasagar, W. H. Watson, A. Nagl and R. P. Kashyap, *J. Org. Chem*., 1991, **56**, 282; J. S. Josan and F. W. Eastwood, *Aust. J. Chem*., 1968, **21**, 2013; G. Crank and F. W. Eastwood, *Aust. J. Chem*., 1964, 17, 1392; M. Ando, H. Ohhara and K. Takase, *Chem. Lett*., 1986, 879; R. R. Sauers and P. A. Odorisio, *J. Org. Chem*., 1979, **44**, 2980; R. W. Hoffmann and M. Reiffen, *Chem. Ber*., 1977, **110**, 49.

8 Heating orthoesters of 1,1,2,2-tetraethynylethanes, such as **4**, in 1,2-dichlorobenzene to 170 °C in the presence of catalytic amounts of HI produces the corresponding tetraethynylethenes in around 50% yield; P. Siemsen, S. Kammermeier and F. Diederich, unpublished results; M. Konieczny and R. G. Harvey, *J. Org. Chem*., 1980, **45**, 1308.

9 E. Kloster-Jensen and J. Wirz, *Helv. Chim. Acta*, 1975, **58**, 162; E. Kloster-Jensen and J. Wirz, *Angew. Chem., Int. Ed. Engl*., 1973, **12**, 671; H. N. C. Wong. P. J. Garratt and F. Sondheimer, *J. Am. Chem. Soc*., 1974, **96**, 5604; R. Destro, T. Pilati and M. Simonetta, *Acta Crystallogr., Sect. B*, 1977, **33**, 447; R. Gleiter and R. Merger, in *Modern Acetylene Chemistry* ed. P. J. Stang and F. Diederich, VCH, Weinheim, 1995, p. 285.

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