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INTERCYCLIC vs. INTRACYCLIC $[\Pi 2+\sigma 2+\sigma 2]$ / $[\Pi 2+\Pi 2]$ CYCLOADDITION REACTIONS IN STERICALLY FIXED NORBORNADIENE/QUADRICYCLANE SYSTEMS**

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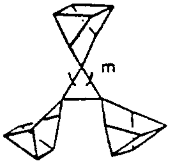
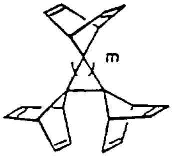
Summary: In specifically designed substrates, the geometrical/stereoelectronic factors governing inter-/intracyclic thermal $[_\pi 2+_\sigma 2+_\sigma 2]$ and photochemical $[_\pi 2+_\pi 2]$ cycloaddition reactions are studied.

Cyclic quadricyclanylidene(Q)/norbornadienylidene(N)oligomers of types **A**/**B** are of interest to us as substrates for the experimental verification of unusual thermal $[_\pi 2+_\sigma 2+_\sigma 2]$ and photochemical $[_\pi 2+_\pi 2]$ cycloaddition cascades[1].

A

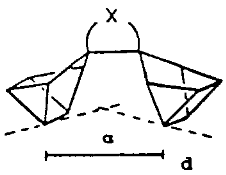




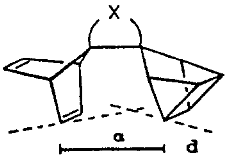
B

Using models of type **D**/**E** (prepared from **C**), the geometrical/stereoelectronic prerequisites (d,α) for efficient intercyclic bond formation are being elucidated. As expected, intracyclic stabilization ($-[_\sigma 2+_\sigma 2]$, $[_\pi 2+_\pi 2]$) dominates in the systems **D**/**E** with central three-membered rings (X=CH_2,O), intercyclic stabilization ($[_\pi 2+_\sigma 2+_\sigma 2]$; $[_\pi 2+_\pi 2]$), however, in the systems with central five-membered rings (X=$OC(CH_3)_2O$)[2]. For the four-membered systems **D** and **E** the experimental outcome seemed open, and for the non-planar six-membered examples **D** and **E** intercyclic additions should be bound to conformations with parallel N/Q-units. We report here the synthesis and thermal/photochemical behaviour of **D**-/**E**-substrates with central four-/six-membered rings.

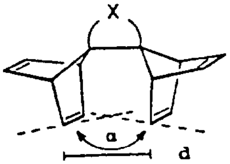
C



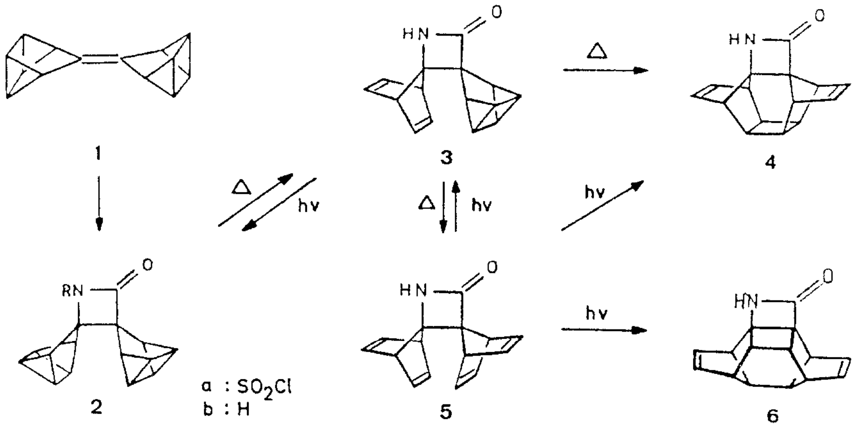
D



E

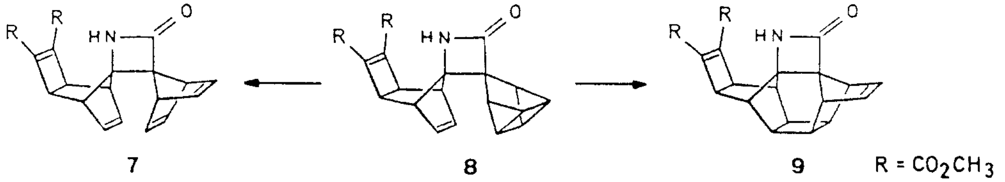


Cycloadditions to the electron rich tetrasubstituted C=C double bond of biquadricyclanylidene **1** (IP=7.7 eV), now readily available[3], are severely hindered for steric reasons[4]. A preparatively useful way to attach a four-membered ring to **1** was found in the reaction with chlorosulfonyl isocyanate (CSI)[5]. When treated with equimolar amounts of CSI (CH_2Cl_2) at temperatures below -60°C, quantitative addition occurred to give the 1:1 adduct **2a**[6]. Above 0°C, **2a**, in solution and also in the solid state, polymerizes, most probably via a stabilized 1,4-dipole. Cleavage of **2a** to give **2b** was brought about by treatment with Na_2SO_3 (aq.) (-20°C->0°C, 65-70%). When the reduction was performed with 2.0/1.2 equiv. thiophenol/pyridine at -45°C, ca. 35% each of **3** and **4** were isolated (besides traces of **2b** and addition products)[7].



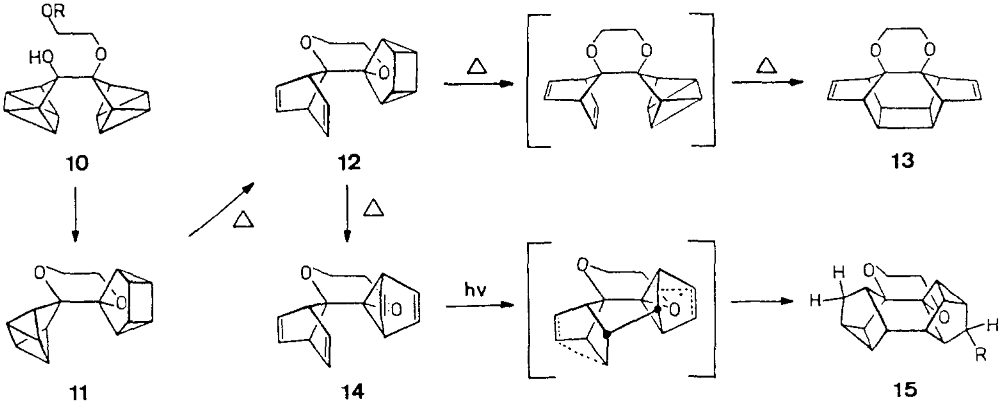
Heating **3** in a ca. 0.4 M degassed benzene solution at 120°C (total conversion, 12 h) yielded ca. 90% of a 6:1 mixture of intercyclic $[_{\pi}2+_{\sigma}2+_{\sigma}2]$ adduct **4** (m.p. 258°C, N-acetyl derivative m.p.130°C) and tetraene **5** (m.p. 200°C (dec.)). Lactam **5** was conventionally prepared from **2b** with 6 mol-% $PdI_2[Sb(C_6H_5)_3]_2$ catalyst (88%). Acetone-sensitized excitation of **5** (degassed 0.02 M solution, 25°C, Hanau high pressure mercury lamp, 150 W) lead to a 2:1 mixture of **4/6**[8] (80% isolated, **3** and **2b** each <1%, additional **4** isomers ca. 15%). Upon direct irradiation (0.02 M $CHCl_3/CH_3CN$ (1:1) solution, 25°C, ca. 50% conversion), the two monomers **3/4** were formed in the ratio 66:34 (85%, rest polymers).

Even more than with **3**, the $[_{\pi}2+_{\sigma}2+_{\sigma}2]$ cycloaddition prevails in substrate **8**: Upon heating (0.22 M benzene solution, 135°C), ca. 90% of a 5:95 mixture of **7** (m.p. 155°C) and **9** (m.p. 138°C) (**8→7**: $\Delta G^{\ddagger}$=32.9 kcal/mol)[9]; **8→9**: $\Delta G^{\ddagger}$=31.0



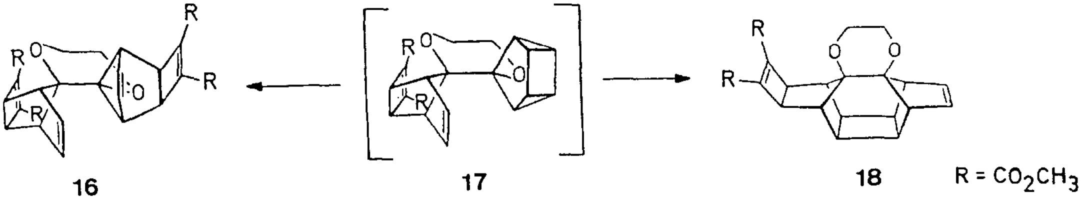
kcal/mol) were isolated. Monoadduct **8** is exclusively formed (90%; mp. 148°C, no addition from the C=O-side) when **2b** is heated with 3.5 equiv. of dimethyl acetylenedicarboxylate in boiling chloroform.

The "tetracyclopropylethylene" **1** did not undergo [4+2] addition with a variety of dienes (e.g. α-pyrone, tetrachlorothiophene dioxide, dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate). The 1,4-dioxane-anellated derivative **11** was finally constructed via the epoxide of **1**[2,10]. From the reaction with ethylene glycol under carefully controlled S_N2-borderline conditions the diol **10a** was obtained in ca. 70% yield (besides one of the two possible mononorbornadiene-isomers). Cyclization **10b**→**11** was conveniently effected by stirring the pyridine solution over silica gel (60%, not optimized, m.p. 74°C)[11]. Through catalytic isomerization, **12/14** became available (>90%). At ca. 30°C, the NMR spectra (250 MHz, $CDCl_3$) of **11/12** (C_{2v}) manifest fast, for **14** (C_2) slow conformational changes. As expected, increasing steric compression between the four inner hydrogens opposes the parallel orientation of the Q/N-units (for **14** at 135°C (T coalesc., C_6D_5Br) $\Delta G^{\ddagger}$ ca.20 kcal/mol).



Heating **12** in ca. 0.4 M degassed benzene solution at 100°C ($t_{1/2}$ ca. 26 h) furnished ca. 90% of a 3:1 mixture of intercyclic adduct **13** (m.p. 115°C) and tetraene **14** (m.p. 93°C). Clearly, the $[_\pi 2+_\sigma 2+_\sigma 2]$ addition, which is nearly quantitative in the five-membered system **D** (X=OC(CH_3)$_2$O, $t_{1/2}$(80°C) ca.2 h), is less exclusive in non-planar **12** than in **3**. When ca. 0.06 M acetone solutions of **14** were irradiated at 25°C (Hanau high pressure mercury lamp, 80 W, 2 h), neither inter-(**13**) nor intracyclic addition isomers (**11/12**, resp.), instead a 2:1 mixture of **15a/b** (intercyclic H_2/acetone addition) was found (60%, rest polymers). Direct excitation (0.01 M in CH_3CN, 25°C) with monochromatic 254 nm light causes complete polymerization.

Inhibition of intercyclic $[_\pi 2+_\sigma 2+_\sigma 2]$ addition (in **17**) became also evident in the reaction of **11** with excess (2.5 equiv.) dimethyl acetylenedicarboxylate



(benzene, 110°C, 48 h). In a complex product mixture, separated by "reversed phase" HPLC (CH_3OH/H_2O 65:35), only 30% of the intercyclic adduct **18** (m.p. 192-193°C) were present besides 30% of bis-adduct **16** and 10% of at least 2 additional adducts.

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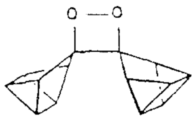
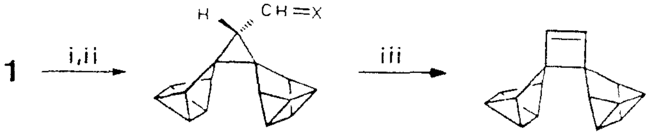
2) H. Prinzbach, K. Weidmann, S. Trah, L. Knothe, Tetrahedron Lett. **22** (1981) 2541; cit. lit.
3) The originally reported yield (20%) of **1** based on quadricyclanone was raised to 75%: K.-H. Lehr, dissertation, Univ. Freiburg 1980.
4) Attempts to add dichloroketene (generated in situ from $CHCl_2COCl$/ NEt_3 or CCl_3COCl/Zn) only gave poor addition to the central C=C-bond; polymerization and $Zn(ZnCl_2)$-catalyzed quadricyclane → norbornadiene isomerization compete efficiently. In contrast, diphenylketene added to give enolether adducts of the quadricyclane moiety; cp. J. Becherer, N. Hauel, R. W. Hoffmann, Liebigs Ann. Chem. **1978**, 312. Tetraphenylphorphyrine (TPP)-sensitized photooxidation of **1** ($CDCl_3$, -60°C) yielded the labile dioxetane **19** ($t_{1/2}$(-60°C)=70 min; ^1H-NMR:δ=1.97(4H), 1.90(4H), 1.81(4H)). The unusual addition mode of N-phenyl-1,2,4-triazolinedione is detailed in: K.-H. Lehr, J. Werp, H. Bingmann, C.Krüger and H. Prinzbach, Chem. Ber. **115** (1982) 1835. **1** also resists diimide-reduction and addition of tosylazide.
In preliminary attempts, the cyclobutene **21** was constructed via thermolysis of the Li-salt of **20** (X=NNHTos). (i): Ethyldiazoacetate/CuCN/cyclohexane (ca. 30%); (ii): LAH/THF (89%); pyridinium dichromate (74%); (iii): n-BuLi; THF, 110°C (40% **1**+**21**).

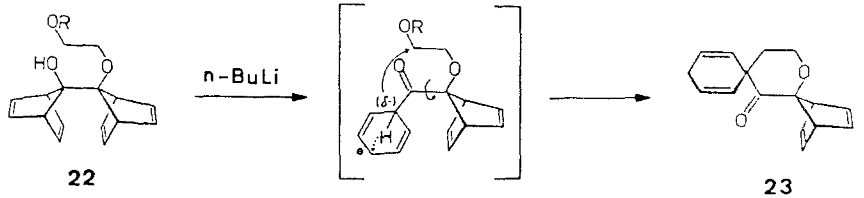


19



20 **21**

5) R. Graf, Liebigs Ann. Chem. **661** (1963) 111; J.K. Rasmussen, A. Hassner, Chem. Rev. **76**, (1976) 389; cp. also L.A. Paquette, M.J. Broadhurst, J. Org. Chem. **38** (1973) 1893.
6) All new compounds are fully analyzed by elemental analysis and spectra (IR, UV, MS, ^1H-, ^{13}C-NMR).
7) The selective formation of N,Q-isomer **3** (for azetidinones $^3J_{(C-3,NH)}$=11-12 Hz are characteristic; decoupling experiments indicate that C-3 of the quadricyclane moiety is C-3 of the β-lactam ring) may be explained in terms of intercyclic bond formation/ isomerization in an intermediate amidyl radical.
8) The by-product (ca. 15%) in the acetone-sensitized excitation of the analogous N,N-compound of the (5)-series[2] has been shown to arise from the same type of diradical stabilization (two 1,2-vinyl shifts).
9) D.S. Kabakoff, J.-C.G. Bünzli, J.F.M. Oth, W.B. Hammond, J.A. Berson, J. Am. Chem. Soc. **97** (1975) 1510.
10) M. Bruch, Y.M. Jun, A.E. Luedtke, M. Schneider, J.W. Timberlake, J. Org. Chem. **51** (1986) 2969.
11) In contrast, efforts to cyclize **22** to **14** resulted in the formation of **23** (87%).



22 **23**

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