

Tetrahedron 55 (1999) 12783-12796

Thiocarbonyl Ylides and Electrophilic Azo Compounds; Sterically Hindered Cyclic Hydrazodicarboxylic Esters ¹

Rolf Huisgen,^{*} Xingya Li, Grzegorz Mloston,² Rudolf Knorr, Helmut Huber, and David S. Stephenson

> Institut für Organische Chemie der Universität München Butenandtstr. 13, D-81377 München

Received 30 August 1999; accepted 3 September 1999

Abstract: The cycloadduct 5, prepared from adamantanethione S-methylide with dimethyl azodicarboxylate, exists in solution in two conformations P and Q (70:30 in CDCl₃), which are separated by a barrier of ΔG^{+} 18.3 \pm 0.6 kcal mol⁻¹; according to NMR spectra, both forms are chiral. Steric hindrance to 3'N-CO₂CH₃ rotation by the adamantane system generates C=O outside and C=O inside conformations. The barrier to enantiomerization (AB \rightarrow A₂ for 5'-H₂) is higher (> 20.1 kcal mol⁻¹). Three combinations of rate processes are discussed. Except for the 5'-methyl compound 19a, the chiral cycloadducts of four other thiocarbonyl ylides to dimethyl azodicarboxylate do not show diastereoisomeric conformations in their NMR spectra at ambient temperature. © 1999 Elsevier Science Ltd. All rights reserved.

Adamantanethione S-Methylide

The readily available 2,5'-dihydrospiro[adamantane-2,2'-(1,3,4)-thiadiazole] (2) eliminates N_2 at 40°C in THF with a half-reaction time of 90 min.³ The nucleophilic 1,3-dipole 3 undergoes [3+2] cycloadditions with electrophilic multiple bonds: Ethylene and acetylene derivatives with electron-attracting substituents,⁴ thiocarbonyl compounds, aldehydes, and imines.⁵



N-Acylazo compounds are strong electrophilic reagents. After heating of 2 with 1.05 equiv of dimethyl azodicarboxylate (4) for 8 h at 40°C, ¹H NMR analysis indicated 90% of 5. In the MS of the thiadiazolidine derivative 5, the molecular peak appears with 99% intensity, and scheme 6 discloses four fragmentation pathways. The molecular formulae of the fragments were confirmed by the intensities of ¹³C and $({}^{34}S+{}^{13}C_2)$ isotope peaks. The base peak, m/z 208, is devoid of sulfur and corresponds to $C_{12}H_{18}NO_2^+$; it would fit the iminium formula 7 or an isomeric structure. $C_{12}H_{17}NO_2S^+$ for m/z 239 (60%) results from another cleavage and is in accord with $[M^+-H_2C=N-CO_2CH_3]$. The splitting of M⁺ along the line of the original cycloaddition is of minor importance: m/z 180 (13%) for the radical cation of 3.



Hindered Rotation in the Adduct 5 of Dimethyl Azodicarboxylate

If the two carbamic ester groups were regarded as *quasi*-coplanar, 5 should have C_s symmetry, and a reduced set of ¹³C signals for the adamantane C-atoms would be anticipated: three CH₂ (2:2:1), three CH (2:1:1), and the quaternary C-2. In contrast, the ¹³C NMR spectrum (100 MHz, CDCl₃, 25°C) of the pure 5 indicates a 70:30 mixture of two conformers, **P** and **Q**, both of which display ten different ¹³C signals for the adamantane part, thus revealing *chirality*: five CH₂ and four CH signals at δ 26 - 38, and the C-2 at δ 89.5 (**P**) and 89.1 (**Q**). The resonances of C-2 and C-5' are shifted to higher frequencies by S and N functions. The C-atoms of C=O and OCH₃ occur likewise in pairs with height ratios of 70:30.

In the ¹H NMR spectrum (400 MHz, CDCl₃, 25°C) of 5, two AB patterns for 5'-H₂ (δ 4.41, 4.93 for **P** and 4.49, 4.80 for **Q**) confirm the ratio of 70:30 for the slowly equilibrating forms. **P**/**Q** = 68:32 in Cl₂CD-CDCl₂ and 66:34 in C₆D₅NO₂ show a small influence of the solvent. The *gem*-coupling constant of 5'-H₂, ²J = 7.8 - 8.1 Hz, is diminished by the proximity of two heteroatoms.⁶ Two ester methyl singlets each for **P** and **Q** appear in the narrow range of δ 3.65 - 3.80.

Before the hindered rotation is discussed in the light of previous evidence, the temperature dependence of the NMR spectra will be considered. At 25 °C, sharp ¹³C signals demonstrate slow interconversion of **P** and **Q** and allow an unambiguous pairwise ordering. The ¹³C re-

sonances at 50°C disclose various stages of line broadening and coalescence. At 120°C (Cl₂CD-CDCl₂) the equilibration is fast, and *one* set of ten adamantane signals establishes that *chirality is retained*.

According to 400 MHz ¹H NMR spectra, coalescence of corresponding OCH₃ singlets of **P** and **Q** was observed at 40-65°C in three solvents. In C₆D₅NO₂, $\Delta \nu$ 8.1 and 14.5 Hz were found for the two OCH₃ pairs at 25°C, but T_c 65°C resulted for both pairs as a consequence of different temperature dependencies of $\Delta \nu$; in Fig. 1 the asymmetry of band shapes is noticeable. All changes from 25° - 150°C were found to be fully reversible. On cooling of the CDCl₃ solution to -50°C, some line broadening, but no further splitting of the ¹H resonances was observed.

Figure 1. Coalescence in the ¹H NMR spectra ($C_6D_5NO_2$, 400 MHz) for the OCH₃ singlets of conformations **P** and **Q** of 5.



The AB spectra of 5'-H₂ for **P** and **Q** enter coalescence, in the A and B part separately, with T_c 68° - 96°C (Table 2), until *one* AB spectrum remains at higher temperatures; the doublet signals are not separated at the basis. Heating to 120°C (Cl₂CD-CDCl₂) and 150°C (C₆D₅NO₂) is accompanied by further signal broadening, but coalescence for AB \rightarrow A₂ is still not reached.

Applying the band shape equation for unequal concentrations of equilibrium partners,^{7,8} nine values of T_c and Δv for the merging of P and Q allowed the determination of nine values of k_c and hence ΔG_c +. ΔG_P + and ΔG_Q + differ by the free equilibrium enthalpy. The evaluated ΔG_P + ranges from 17.7 to 18.7 kcal mol⁻¹ with 18.3 ± 0.6 kcal mol⁻¹ as averaged value (Table 2). No distinct solvent influence was observed. The T_c of the next dynamic process, which should make the diastereotopic 5'-H₂ enantiotopic (AB \rightarrow A₂), must be significantly above 150°C; $\Delta G_{+} > 20.1$ kcal mol⁻¹ was calculated for 150°C by the expression for the coalescence AB \rightarrow A₂.⁹

Discussion

Electron diffraction data of hydrazine (gas) reveal a dihedral angle of 91(2)° between the lone-pair orbitals.¹⁰ Ab initio calculations also favor a nearly orthogonal arrangement rather than *trans*-located n-orbitals; at STO-4LGF level, $\Theta = 95^{\circ}$ was obtained for the energy minimum, and rotational barriers of 10.8 and 4.2 kcal mol⁻¹ resulted for $\Theta = 0^{\circ}$ (n-orbitals eclipsed) and 180°, respectively.¹¹

The interplay of N inversion and N-N rotation in substituted hydrazines has been a much studied problem.¹² The resonance effect resulting from N-acylation tends to planarize the nitrogen bond system. 1,2-Diformylhydrazine has a planar conformation with $\Theta = 180^{\circ}$, due to the presence of two intramolecular hydrogen bonds (X-ray,¹³ neutron diffraction ¹⁴). In 1,2-diformyl-1,2-dimethylhydrazine (8), two planar *N*-methylformamide units are orthogonally arranged ($\Theta = 91.2^{\circ}$),¹⁵ revealing the same conformational preference as hydrazine itself.

The topomerization of the benzyl protons in the N-acetylhydrazine 9 requires N – N rotation via a barrier of ΔG_{341} + 15.5 kcal mol⁻¹.¹⁶ A rotational barrier of 23.5 kcal mol⁻¹ (T_c 192°C) was reported for the hydrazodicarboxylate 10.¹⁷ We must conclude that N-acylation *decreases* the N inversion barrier, but *increases* the barrier to N – N rotation; this is an unexpected effect since the delocalization of the unshared electron pair should diminish the repulsion of the n-orbitals. *Non-bonded interaction* between the carbamate groups was invoked to explain the high rotational barriers of hydrazodicarboxylates.^{17,18b}



In now classic papers, the research groups of Lehn ¹⁸ and Sutherland ¹⁹ studied the temperature dependence of the ¹H NMR spectra of cyclic hydrazodicarboxylates and observed *two* dynamic processes; *e.g.*, for 11 barriers of ΔG + 20.7 and 14.7 kcal mol⁻¹ were determined.^{19b} The higher one was attributed to ring inversion, also called "bridge flipping"; Anderson and Lehn supposed the passing of a *quasi*-coplanar transition state (TS) of the two carbamic ester groups by twisting about the N-N bond.^{18b} At lower temperature, the number of ester alkyl signals increased; the authors assumed that it is the rotation about the N-CO₂CH₃ bond (ΔG + 14.7 kcal mol⁻¹ at -3°C) which becomes frozen.

As long as the carbamate group was regarded as nearly planar,^{18b} the bicyclic diester 12 with its rigid 5-membered ring should approach the *quasi*-coplanar TS for the ring inversion of 11.^{12a} Due to the raising of the ground state of 12, the ¹H NMR spectrum did not disclose a torsional barrier of the N – N bond. The barrier to rotation of N – CO_2CH_3 (13.9 kcal mol⁻¹ at -5°C) was similar to that observed for 11.^{18c,19b}

The group of Sutherland presumed that the N atoms of the bicyclic 12 are somewhat pyramidal.^{19b} A confirmation came from a later X-ray analysis of 13 by Offereins et al.²⁰ The two planar ester groups are located *exo* and *endo* at the bicyclic system; the dihedral angle at C1-N2 – N3-C4 is only 0.4°, but that of OC-N2 – N3-CO amounts to about 90°. Nelsen recommended $\alpha(av)$, a third of the angle sum at the N atom, as a measure of pyramidality (120° for planar-trigonal, 109.5° for tetrahedral).^{12b} Values of $\alpha(av) = 113.9$ (N2) and 113.2° (N3) for 13 indicate substantial pyramidality. Obviously, the repulsive force between *cis*-coplanar amide groups was previously underestimated; in addition, the strain of the rigid 5-membered ring favors pyramidalization. The bicyclo[2.2.1]heptane system does not allow much freedom to the angle C1-C2-C3: 103-104° in norbornane ^{21,22} and norbornene.²³ Bond angle C1-N2-N3 is 105° in 13.²⁰

We are not aware of data on structures and inversion barriers of *monocyclic 5-membered* hydrazodicarboxylates. The 5-membered ring in 5 is more flexible than that in the bicyclic 12 or 13 and can accommodate somewhat larger bond angles, *i.e.*, N hybridizations between sp^3 and sp^2 , with less strain energy.

Regrettably, we did not so far obtain suitable monocrystals of 5 for X-ray diffraction. According to molecular models, the adamantane system enforces twisting of the $3'N - CO_2CH_3$ of 5, thus decreasing the carbamate resonance and increasing the pyramidalization at 3'N. A substantial barrier separating a C=O outside and C=O inside conformation is anticipated. The energy maximum in the rotational profile of RR'N - CO₂CH₃ of 12 (13.9 kcal mol⁻¹) occurs at 90°, and the minimum near planarity. However, for $3'N - CO_2CH_3$ rotation of 5, the maximum should be close to 0° where the van der Waals pressure in the collision with the voluminous adamantane group is greatest, but the gain in carbamate resonance provides partial compensation. At the minimum, the carbamate conjugation is strongly disturbed.

An AM1 calculation of 5 confirms C=O outside and C=O inside conformations – the first is by nearly 2 kcal mol⁻¹ better than the second – as minima on the potential surface (Fig. 2).²⁴ Additional minima are generated by two nearly planar conformations of $4'N - CO_2CH_3$; the slightly better one is illustrated in Fig. 2. The heteroring is recognized as an envelope conformation with C2 as the flap, thus diminishing the van der Waals pressure. The distance from carbonyl oxygen (3'N-CO₂CH₃) to the closest nonbonded neighbor, the 4-H of adamantyl, is 2.18 Å (5A) and 2.15 Å (5B).

Both N atoms are pyramidalized, N3' stronger than N4', as shown for 5A by $\alpha(av) = 111.9^{\circ}$ and 116.9°, respectively. In the *outside* form 5A (*inside* form 5B), the O=C-O plane cuts the plane C2-N3'-C(O) at an angle of 81° (79°); thus, the conjugation 3'N-CO is virtually extinct. As for 4'N-CO₂CH₃, the interplanar angle between C5'-N4'-C(O) and O=C-O amounts to 9° (5A) and 7° (5B), asserting conjugative coupling. We will abstain from further numerical evaluation since the weakness



Figure 2. C=O outside (5A, left) and C=O inside conformation (5B, right) calculated by AM1.

of the semiempirical AM1 in reproducing diacylhydrazine structures is well-known;²⁵ also the basis set for sulfur bonding is unsatisfactory.

What is the nature of the barrier (18.3 kcal mol⁻¹) separating **P** from **Q** (70:30) ? Why does the high-temperature NMR spectrum still indicate chirality ? Three possibilities will be discussed.

Model 1. The chiral forms P and Q, observed in the NMR spectra, correspond to 5A and 5B. The 18.3 kcal mol⁻¹ barrier belongs to the rotation of $3'N - CO_2CH_3$ which interconverts 5A and 5B. The higher barrier of > 20.1 kcal mol⁻¹ (T_c above 150°C) is ascribed to the ring inversion by N - N torsion; this enantiomerization will change the AB spectrum of 5'-H₂ into A₂.

At first glance, a significantly lower inversion barrier would be expected for the 5-membered ring of 5 than for the 6-membered of 11, hydrogenated at the double bond (19.4 kcal mol⁻¹).^{18d} The comparison of the inversion barrier of the cyclohexane chair (ΔH + 10.7 kcal mol⁻¹) with the "conformational flux" of the cyclopentane envelope (2.8 kcal mol⁻¹ for pseudorotation) ²⁶ is pertinent. Assuming that the N – N twisting consists essentially of two consecutive N inversions, the loss of carbamate resonance at 3'N – CO₂CH₃ is a destabilization of the ground state and should facilitate the process. On the other hand, it is difficult to estimate the hindrance to the N inversion by the adamantane system. Barriers to N – N rotation in hydrazodicarboxylic esters with 6-membered ring are sensitive to small structural changes,¹² but systems with strong steric interference on *one* side have not been studied.

Model 2. The lower barrier (18.3 kcal mol⁻¹) is due to N-N torsion and the higher is attributed to the $3'N-CO_2CH_3$ rotation. The N-N torsion exchanges C=O outside and C=O inside conformations. The single molecule undergoes a diastereoisomerization leading from 5A to the enantiomer of 5B and vice versa. The equilibrating pairs,

$$(R)$$
-P \rightleftharpoons (S) -Q and (S) -P \rightleftharpoons (R) -Q,

occur as 50:50 mixture, but chirality is retained. It is the $3'N - CO_2CH_3$ rotation which finally generates *quasi* symmetry at high temperature. The changed barrier assignments relieve some of the flaws of *model 1* and offer higher consistency.

However, we have neglected so far rotamers of $4'N - CO_2CH_3$ as a further stereoelement. For the rotation of $(CH_3)_2N - CO_2CH_2C_6H_5$, ΔG + 15.9 kcal mol⁻¹ at 17°C was measured, ^{19a} and values of 12.6 - 16.0 kcal mol⁻¹ have been reported for $N - CO_2R$ rotation of various 6-membered cyclic hydrazodicarboxy-lic esters.^{12b} As mentioned, the ¹H NMR signals of 5 show some line broadening on cooling to -50°C, but

no further splitting. It is uncertain, whether extreme equilibrium concentrations or small differences of chemical shifts (Δv) can be responsible for the non-occurrence.

Model 3. The two stable conformations of $4'N - CO_2CH_3$ are both conjugated, but still slightly pyramidal at nitrogen; they occur 70:30 and are ascribed to P and Q. When their interconversion barrier is 18.3 kcal mol⁻¹, then the equilibration of the C=O outside and C=O inside conformations - 5A with the enantiomer of 5B and vice versa - must be fast on the NMR time scale, down to -50°C. This third solution of our DNMR problem would require increasing barriers: N-N torsion < $4'N - CO_2CH_3$ rotation (18.3 kcal mol⁻¹) < $3'N - CO_2CH_3$ rotation (enantiomerization). However, no statement about the ratio of 5A and 5B is feasible. With an energy difference of ~ 2 kcal mol⁻¹ (AM1 calculation), the second form may not become visible in the NMR spectra.

The more flexible heterocycle in 5 has a lower ring strain than 12. On the other hand, the loss of carbamate resonance in the twisted $3'N - CO_2CH_3$ of 5 raises the energy of the ground state. It is conceivable for the process (R)-5A \rightleftharpoons (S)-5B that the ester group glides along the surface of the adamantane sphere without N - CO_2CH_3 rotation. Taking the low pseudorotation energies of the 5-membered ring into account, the N - N torsion might well be the fastest of the three motions in 5.

It may be recalled that only *one* dynamic process was found in the NMR spectra of 12 and related compounds, and there is good reason to attribute the barrier of 13.9 kcal mol⁻¹ to $N - CO_2CH_3$ rotation.^{18,19} However, none of the rotational barriers, described for $N - CO_2R$ above, reached 18.3 kcal mol⁻¹, discussed here for $4N' - CO_2CH_3$; we do not see an obvious reason for the increase.

None of the three interpretations of the DNMR phenomena of 5 is fully satisfying; presently, we leave the decision between *models 2* and 3 open. More data on 5-membered cyclic hydrazodicarboxylic esters are desirable. Admittedly, not all the energy values reported for the 6-membered cyclic bis-carbamates 12 fit a consistent pattern either.

Cycloadducts of Further Thiocarbonyl Ylides with Dimethyl Azodicarboxylate

For the preparation of the 5'-methyl compound 17a, diazoethane was added to adamantanethione (1). Whereas diazomethane and 1 furnish both the 1,3,4- and the 1,2,3-thiadiazoline, depending on solvent polarity,^{3,27} the reaction with diazoethane provided 93% of the crystalline 1,3,4-thiadiazoline 17a; there was no evidence for the occurrence of the regioisomer, as also noticed by Katada *et al.*²⁸ The N₂ elimination in toluene at 81°C proceeds with $t_{1/2}$ 2.6 min; the 5'-methyl slows down the rate, measured for 2,³ by a factor of 2.8. The N₂ extrusion from 17a in the presence of 1.1 equiv of 4 furnished 93% of cycloadduct 19a.

The ¹³C NMR spectrum of **19a** (CDCl₃, 25°C, 100 MHz) shows a double set of ten adamantane signals, as described above for the ¹³C parameters of **5**. With 72:28 even the ratio of conformations **P** and **Q** is similar as that observed for **5**. C-5' and 5'-CH₃ as well as the carbonyl and methoxy groups of 3'-CO₂CH₃ and 4'-CO₂CH₃ appear likewise in doubled signals. The ¹H NMR spectrum confirms the presence of only two chiral conformations **P** and **Q**; *e.g.*, two quartets for 5'-H, two doublets for 5-CH₃, and four ester methyl signals appeared.

C-5' is an additional stereocenter in the 19a, but no further increase of conformers was observed. It cannot be excluded, that the signals of further conformations, P' and Q', remain below the analytical limit. No extra signals appeared. That poses a tough problem to interpretations by *models 1-3*. Conceivably, eclipsing effects by 5'-CH₃ curb the populations of various conformers. A detailed discussion should be postponed until the temperature dependence of the NMR spectra has been studied.



Dimethyl azodicarboxylate was reacted with four more thiocarbonyl ylides, 15b,c,d and 18d. The crystalline cycloadducts (Table 1) 16b,c,d show in their NMR spectra only *one* AB pattern for diastereotopic 5'-H₂ at room temperature. All the groups $R_2 = a - d$ will exert steric hindrance to the $3N - CO_2CH_3$ rotation.

| | NMR Parameters (CDCl ₃ , 25°C) | | | | | 1,3,4-Thiadiazolidine | | | |
|------|---|----------------------|-------------------|-----------------------|---|-----------------------|--------|--------------|--|
| | - | δ _H (ppm) | | δ _C (C-5') | | mp (°C) | %Yield | Formula | |
| | 4.93 | 4.41, | 5'-H ₂ | 48.70 | P | 112-113 | 93 | 5 | |
| | 4.80 | 4.49, | - | 48.76 | Q | | | | |
| 1.50 | 5'-CH ₃ | 5.44 | 5'-H | 60.99 | P | 87-89 | 93 | 1 9 a | |
| 1.48 | - | 5.33 | | 61.04 | Q | | | | |
| | 5.13 | 4.63, | 5-H ₂ | | | 98-100 | 72 | 16b | |
| | 5.50 | 4.86, | 5'-H ₂ | 52.3 | | 1 69- 171 | 88 | 1 6 c | |
| | 4.58 | 4.38, | 5'-H2 | | | 110-112 | 58 | 16d | |
| 1.52 | 5'-CH ₂ | 5.22 | 5'-н | | | 117-119 | 63 | 19d | |

Table 1. Cycloadducts of thiocarbonyl ylides with dimethyl azodicarboxylate

The 5'-methyl-1,3,4-thiadiazoline 17d was prepared from 20 with diazoethane and converted to the cycloadduct 19d as usual. The ¹H NMR spectrum of 19d displays *one* AX_3 spectrum, due to 5'-H(CH₃).

Thus, the occurrence of equilibrating diastereoisomers appears to be a unique feature of the adamantane series, for which we have no good argument. Among the three interpretations, proposed above, *model* 3 faces the greatest difficulties. Why should the distant R_2 influence either the ratio of the two conjugated conformations of $4'N - CO_2CH_3$ or their rate of equilibration so strongly ? Only further studies can shed light upon the interplay of phenomena.

Steric hindrance is an ambiguous term. When rate constants are used for establishing increasing steric demand for a series of groups, the sequence may highly depend on the nature of the reaction considered. *Size and shape* of the groups will determine the degree of hindrance. In 1,3-dipolar cycloadditions with thiobenzophenone, adamantanethione (1) and thione 20, the rate ratios vary widely.²⁹

4-Phenyl-1, 2, 4-triazoline-4, 5-dione

The cyclic diacylazo compound 21 belongs to the most potent dienophiles and dipolarophiles. The in situ cycloadditions of the thiocarbonyl ylides 2 (at 40°C) and 15b (at -45°C) furnished the triazolidines 22 (55%) and 23 (87%), respectively. A sharp singlet for 5-H₂ was found in both of the ¹H NMR spectra.



Several Diels-Alder adducts of 21 with cyclic dienes were subjected to X-ray analysis by Kaftory et al.³⁰ The diacylimide ring of 24 is close to planar, but γ 128.3° demonstrates the non-planar annulation. The disadvantage of having the lone pairs at the two N atoms in parallel p-orbitals is avoided by strong pyramidalization: $\alpha(av) = 110.5^{\circ}$ is close to the tetrahedral angle. The strain in the bridged pyrazolidine ring likewise promotes N pyramidality. A dynamic process in a related compound was ascribed to a simultaneous double N inversion (ΔG + 8.7 kcal mol⁻¹ at -72°C), i.e., the eclipsing interaction of the lone-pair orbitals is retained during the process.^{30c}

EXPERIMENTAL

General.5

Adamantanethione S-Methylide (3)

Dimethyl Spiro[adamantane-2,2'-(1,3,4)-thiadiazolidine]-3',4'-dicarboxylate (5): (a) Dimethyl azodicarboxylate (4, 307 mg, 2.10 mmol) and 2.00 mmol of 2³ in 5 ml of abs. THF were heated at 40°C for 8 h. After evaporation of the solvent, the residue was dissolved in CDCl₂, and a weighed amount of sym-tetrachloroethane (δ 5.92) was added. Comparison of the ¹H NMR integrals of the two d at δ 4.74 and 4.85 with the s of the standard established 1.80 mmol (90%) of 5. Recrystallized from ethanol, 370 mg (57%), mp 112-113°C, was obtained. - IR (KBr): \vec{v} 1282 cm⁻¹ st (C-O); 1480, 1548 st; 1710, 1747 st (C=O). - ¹H NMR (400 MHz, 25°C, isomers P/Q 70:30): δ 1.6 - 2.0 (m, 10 H), 2.25, 2.20 (2 d br, J = 12.5 Hz, 2 H of P and Q), 2.55 (appar. t, 1 H), 2.98 (s br, 1 H); P: 3.745, 3.762 (2 s, 2 OCH₃), 4.41, 4.93 (AB, $J_{gem} = 7.8$ Hz, 5'-H₂); Q: 3.751, 3.798 (2 s, 2 OCH₃), 4.49, 4.80 (AB, $J_{gem} = 7.8$ Hz, 5'-H₂). - ¹³C NMR (100 MHz, DEPT; although unreliable, second decimals are given, because $\Delta\delta$ are often small), Conformer P: δ 26.59, 26.66, 35.34, 37.69 (4 CH), 34.03, 35.01, 36.08, 37.51, 37.74 (5 CH₂), 48.70 (C-5'), 53.41, 53.80 (2 OCH₂), 89.54 (C-2), 155.89, 156.45 (2 C=O); Conformer Q: δ 26.64, 26.66, 35.38, 37.94 (4 CH), 34.57, 35.12, 36.02, 37.55, 37.79 (5 CH2), 48.76 (C-5'), 53.39, 53.86 (2 OCH₃), 89.12 (C-2), 154.12, 156.35 (2 C=O); all signal heights P/Q are 70:30 \pm 2. - MS (MAT 90, 40°C); m/z (%): 326 (99) [M⁺], 293 (12) [M⁺- CH₃OH - H; C₁₄H₁₇N₂O₃S⁺; ¹³C 1.8/1.8], 267 (8.5) $[M^+-CO_2CH_3; {}^{13}C 1.22/1.26], 239$ (60) $[M^+-H_2C=N-CO_2CH_3, C_{12}H_{17}NO_2S^+, {}^{13}C 8.0/7.6;$ $(^{34}S+^{13}C_2)$ 3.1/2.6], 235 (19) [267 - S; ^{13}C 2.8/3.3; no ^{34}S], 208 (100) [M⁺- S-CH=N-CO₂CH₃,

 $\begin{array}{l} C_{12}H_{18}NO_{2}^{+}, \ 7, \ ^{13}C \ 13/12, \ no \ ^{34}S], \ 207 \ (39), \ 206 \ (45) \ [C_{12}H_{16}NO_{2}^{+}], \ 180 \ (13) \ [C_{11}H_{16}S^{+}], \ 166 \ (63) \\ [C_{10}H_{14}S^{+}, \ 1^{+}; \ (^{34}S^{+13}C_{2}) \ 3.1/2.8], \ 165 \ (15), \ 164 \ (15), \ 160 \ (19) \ [M^{+-} 1, \ C_{5}H_{8}N_{2}O_{4}^{+}, \ H_{2}C^{=N^{+}(E)} \\ NE], \ 149 \ (68) \ [208 - CO_{2}CH_{3}, \ C_{10}H_{15}N^{+}], \ 133 \ (21) \ [166 - SH], \ 132 \ (19), \ 117 \ (10), \ 106 \ (10), \ 105 \ (10), \\ 93 \ (16), \ 91 \ (36) \ [C_{7}H_{7}^{+}], \ 88 \ (26) \ [CH_{3}O_{2}C^{-}N^{=}NH \ ?], \ 79 \ (32), \ 77 \ (14). \ - \ Anal. \ for \ C_{15}H_{22}N_{2}O_{4}S \\ (326.4): \ calcd \ C \ 55.19, \ H \ 6.79, \ N \ 8.58, \ S \ 9.82; \ found \ C \ 55.41, \ H \ 7.07, \ N \ 8.53, \ S \ 9.88. \end{array}$

Table 2. Dynamic ¹H NMR (400 MHz) data for the equilibration of conformations P and Q of cycloadduct 5 in various solvents (L = low-frequency signal, H = high-frequency signal; for X, see text)

| T _c (°C) | $\frac{Process}{P + Q}$ | Δν (Hz) | k _P (s ⁻¹) | k _Q (s ⁻¹) | ∆G _P + (kcal n | ∆G _Q ≠ nol ⁻¹) | | | | | | |
|---|-------------------------|------------|--------------------------------------|--------------------------------------|------------------------------|--|--|--|--|--|--|--|
| a. $CDCl_3$, Isomer ratio $P/Q = 70:30$, $X = 2.176$ | | | | | | | | | | | | |
| Ester methyl singlets ($\delta_{H,P}$ 3.745, 3.762; $\delta_{H,O}$ 3.751, 3.798 at 25°C) | | | | | | | | | | | | |
| 40 | L + L | 2.15 | 1.86 | 4.35 | 18.0 | 17.4 | | | | | | |
| b. $Cl_2CD-CDCl_2$; Isomer ratio $P/Q = 68:32$, $X = 2.123$ | | | | | | | | | | | | |
| Ester methyl singlets ($\delta_{H,P}$ 3.646, 3.650; $\delta_{H,O}$ 3.656, 3.673 at 25°C) | | | | | | | | | | | | |
| 37 | L + H | 2.44 | 2.31 | 4.91 | 17.7 | 17.2 | | | | | | |
| 63 | H + L | 10.4 | 9.83 | 20.9 | 18.2 | 17.7 | | | | | | |
| AB Spectra of 5'-H ₂ ($\delta_{H,P}$ 4.30, 4.81; $\delta_{H,O}$ 4.35, 4.69 at 25°C) | | | | | | | | | | | | |
| 68 | L + L | 19.7 | 18.6 | 39.5 | 18.1 | 17.6 | | | | | | |
| 87 | H + H | 56.0 | 53.0 | 113 | 18.4 | 17.8 | | | | | | |
| c. $C_6 D_5 NO_2$, Isomer ratio $P/Q = 66:34$, $X = 2.069$ | | | | | | | | | | | | |
| Ester methyl singlets ($\delta_{H,P}$ 3.76, 3.83; $\delta_{H,O}$ 3.74, 3.80 at 25°C) | | | | | | | | | | | | |
| 65 | L + L | 7.78 | 8.03 | 15.6 | 18.5 | 18.0 | | | | | | |
| 65 | H + H | 8.22 | 8.49 | 16.5 | 18.4 | 18.0 | | | | | | |
| AB Spectra of 5'-H ₂ ($\delta_{H P}$ 4.51, 5.05; $\delta_{H O}$ 4.58, 4.87 at 25°C) | | | | | | | | | | | | |
| 82 | L + L | 28.8 | 29.7 | 57.6 | 18.5 | 18.0 | | | | | | |
| 96 | H + H | 59.3 | 61.2 | 118.9 | 18.7 | 18.3 | | | | | | |

(b) ¹³C NMR spectrum (100 MHz) in $Cl_2CD-CDCl_2$ at 120°C. The δ_C are by 0.2 - 0.4 ppm greater than the weighted averages of P and Q in $CDCl_3$ at 25°C; the assignments are unequivocal. The broadening of some signals shows incomplete "recovery" after coalescence of P and Q absorptions. δ 26.94, 27.00, 35.70, 37.35 (4 CH), 34.36 br, 35.27, 36.30, 37.79, 38.18 (5 CH₂), 48.79 (C-5'), 53.11, 53.58 (2 OCH₃), 89.80 (C-2), 156.54 (2 C=O).

(c) Temperature dependence of ¹H NMR spectrum (400 MHz) in CDCl₃. According to measurements at 12 temperatures from -50°C to +50°C, the $v_{\rm H}$ (OCH₃) are fairly linear functions of T (K) and allow the extrapolation to Δv at T_c (Table 2). The AB spectra of P and Q, due to 5'-H₂, show only small changes of v from -50°C to +50°C; neither splitting nor coalescence occurs, but the lines broaden at +50°C. The variation of the P/Q ratio, determined from the integrals of the AB spectra, is small and within error limits.

The consistency of the 70:30 ratio from the heights of ^{13}C signals is greater.

(d) ¹H NMR spectra in Cl_2CD - $CDCl_2$ from 0°C to 120°C. The small $\Delta\delta_{\rm H}$ of the OCH₃ singlets for **P** did not allow the pairing of **P** and **Q** signals with certainty; 1 + 3 and 2 + 4 furnished more consistent results (Table 2) than 1 + 4 and 2 + 3. The shape of the combined signal after the second coalescence remains asymmetric up to 80°C; the separation of the two sharpening peaks begins at 85°C, but the two signals of 3'- and 4'-CO₂CH₃ at 100°C (δ 3.695, 3.701) are still merged at the base and differ in height. Eleven spectra of the AB systems (5'-H₂) from 0°C to 120°C reveal T_c 68°C and 87°C. $\Delta\nu$ of **P**,**Q** pairs at T_c were obtained by graphic extrapolation. The low-frequency A part is at 100°C a doublet with ²J = 7.6 Hz, whereas the B part appears still as a broad hump. The ratios P/Q at 0 - 40°C fluctuate from 69:31 to 65:35 in the spectral integrals with 68:32 as an average. Therefore, the temperature dependence of the equilibrium constant (**P**/**Q**) was neglected in the evaluation of $k_{\rm P}$ and $k_{\rm Q}$ (Table 2).

(e) ¹H NMR spectra in $[D_5]$ nitrobenzene from 25°C to 149°C. Here, as in the other solvents, the spectrum after returning from the high temp. to 25°C was identical with the original one. The integrals of the AB spectra (5'-H₂) indicated 66:34 as average for P/Q. After coalescence, the d with ²J = 7.5 Hz developed in the A part at 100°C (δ 4.47) and became recognizable in the B part at 137°C (δ 4.90). Before the signals sharpened again, the band broadening at 149°C wiped out the doublet character, due to the beginning of the next dynamic process.

(f) In the bandshape equation for unequal concentrations of equilibrium partners,^{7,8} Δp is the difference of the mole fractions of **P** and **Q**, and the function $X = 2 \pi \delta v \tau_C$ connects the lifetime τ_C with δv at T_C . X was taken from a table of selected Δp values.³¹

$$k_{\mathbf{p}} = (1 - \Delta p)/2\tau_{\mathbf{C}}$$
 and $k_{\mathbf{O}} = (1 + \Delta p)/2\tau_{\mathbf{C}}$

are introduced into the Eyring equation for the evalution of ΔG_{p} + and ΔG_{O} +.

Spiro[adamantane-2,2'-(1,3,4)-thiadiazolidine]-3',4'-dicarbox-(N-phenylimide) (22): 4-Phenyl-1,2,4-triazoline-3,5-dione (21, 2.20 mmol) and 2.00 mmol of 2 in 5 ml of abs. THF were reacted and worked up, as described above. In the quantitative ¹H NMR analysis, the s at δ 4.82 indicated 55% of 22. The methanolic solution deposited 310 mg (44%), mp 156-158°C. - IR (KBr): ν 693 cm⁻¹ w, 759, 768 m (arom. CH out-of-plane deform.), 1402 st; 1494 m, 1595 w (C₆H₅ ring vibr.); 1720 vst, 1768 m (C=O). - ¹H NMR: δ 1.7 - 2.8 (m, 14 H), 4.82 (s, 5'-H₂), 7.2 - 7.5 (m, C₆H₅). Anal. for C₁₉H₂₁N₃O₂S (355.4): calcd C 64.20, H 5.96, N 11.82, S 9.02; found C 64.04, H 6.02, N 11.83, S 9.02.

Adamantanethione S-Ethylide (18a)

2',5'-Dihydro-5'-methylspiro[adamantane-2,2'-(1,3,4)-thiadiazole] (17a): Freshly sublimed adamantanethione (1, 498 mg, 3.00 mmol) in 3 ml of diethyl ether at 0°C was treated dropwise with ethereal diazoethane, until the yellow color persisted. After evaporation, 17a crystallized from pentane at -78°C; 617 mg (93%) of colorless prisms, mp 41-42°C, was obtained (colorless oil).²⁸ - IR (KBr): $\tilde{\nu}$ 1450 cm⁻¹ st (N=N str), 1582 m. - ¹H NMR: δ 1.75 (d, ³J = 7.0 Hz, CH₃), 1.8 - 2.2 and 2.45 - 2.95 (m, 14 H), 5.87 (q, ³J = 7.0 Hz, 5'-H). - MS (30°C); *m/z* (%): 222 (< 1) [M⁺], 194 (71) [M⁺- N₂, 18a⁺], 179 (19), 166 (69) [C₁₀H₁₄S⁺, 1⁺], 162 (100) [M⁺- N₂ - S; no ³⁴S peak], 147 (10), 133 (14) [1⁺ - SH], 119 (29), 105 (52), 91 (70) [C₇H₇⁺], 79 (66). - Anal. for C₁₂H₁₈N₂S (222.3): calcd C 64.82, H 8.16, N 12.60, S 14.42; found C 64.78, H 8.19, N 12.51, S 14.65.

Dimethyl 5'-methylspiro[adamantane-2,2'-(1,3,4)-thiadiazolidine]-3',4'-dicarboxylate (19a): 17a (444 mg, 2.00 mmol) and 322 mg (2.20 mmol) of 4 in 4 ml of absol. THF were stirred at 60°C (oil-bath) for 5 h. After exchange of the THF by CDCl₃, the ¹H NMR analysis (δ 5.24 - 5.55, 2 q, due to 5'-H) showed 93% of 19a. PLC with petroleum ether/acetone (9:1) furnished 487 mg of colorless oil as main fraction which crystallized from pentane: 359 mg (53%), mp 87-89°C. - IR (KBr): \tilde{v} 1234 cm⁻¹, 1252, 1284 st (C-O), 1452 st; 1708, 1741 vst (C=O). - ¹H NMR (400 MHz): P and Q signals ~ 70:30, δ 1.50, 1.48 (2 d, ${}^{3}J = 6.1 \text{ Hz}, 5'-CH_3$, 1.60 - 3.20 (m, 14 H), 3.736, 3.75 (2 s, 2 OCH₃ of P), 3.738, 3.81 (2 s, 2 OCH₃) of Q), 5.44, 5.33 (2 q, ${}^{3}J$ = 6.1 Hz, 5'-H). - ${}^{13}C$ NMR (100 MHz, DEPT): P/Q = 72:28, determined from heights with higher accuracy than from ¹H integrals; adamantane system, P and Q, δ 26.60/26.55, 26.62/26.69, 35.30/35.33, 37.14/37.46 (4 CH), 33.80/34.33, 34.97/35.10, 35.92/35.85, 37.50/37.55, 37.69/37.78 (5 CH₂), 89.99/89.77 (C-2); 22.42/22.81 (5'-CH₃), 53.20/53.40, 53.26/53.31 (2 OCH₃), 60.99/61.04 (C-5'), 155.87/154.36, 156.73/156.63 (2 C=O). - MS (MAT 90, 60°C); m/z (%): 340 (66) [M+; ¹³C 11.7/12.4], 280 (43) [M+- HCO₂CH₃; (³⁴S+¹³C₂) 2.4/2.2], 249 (22) [M+- CO₂CH₃ - S; ¹³C 3.4/3.4, no ³⁴S peak], 239 (69) [M⁺⁻ CH₃CH=NCO₂CH₃, $C_{12}H_{17}NO_2S^+$; ¹³C 9.2/10.4, (³⁴S+¹³C₂) 3.6/3.7, same peak in MS of 5], 221 (11), 208 (100) $[C_{12}H_{18}NO_2^+, 7; {}^{13}C 13.3/13.2, {}^{13}C_2 0.8/1.2, no$ ³⁴S], 207 (9), 206 (18), 205 (9) [cascade as observed for 5], 194 (2.4) $[C_{12}H_{18}S^+, 18a^+]$, 180 (6.0) $[C_{11}H_{16}S^+, 3^+; ({}^{34}S^{+13}C_2) 0.7/0.6], 174 (90) [C_6H_{10}N_2O_4^+, M^{+-}1], 166 (72) [C_{10}H_{14}S^+, 1^+; 1^+; 1]$ $({}^{34}S+{}^{13}C_2)$ 3.6/3.0], 149 (13), 133 (9) [1+ - SH], 115 (13) [C₃H₃N₂O₃+, CH₃O₂C-N=N-C=O+], 103 (26), 91 (17) $[C_7H_7^+]$, 79 (16). - Anal. for $C_{16}H_{24}N_2O_4S$ (340.4): calcd C 56.45, H 7.11, N 8.23, S 9.42; found C 56.52, H 7.06, N 8.02, S 9.51.

Thiobenzophenone S-Methylide (15b)

Dimethyl 2,2-Diphenyl-1,3,4-thiadiazolidine-3,4-dicarboxylate (16b): 4 (1.46 g, 10.0 mmol) was added to the solution of 10.0 mmol of 14b, prepared from 1.98 g of thiobenzophenone and 10 mmol diazomethane in 8 ml of diethyl ether at -78°C.³² After 6 h at -45°C, the solvent was removed, and the residue treated with diethyl ether/hexane: 2.57 g (72%) of 16b, mp 98-100°C (dec) after recrystallization from ether. - ¹H NMR: δ 3.28, 3.46 (2 s, 2 OCH₃), 4.63, 5.13 (AB, ²J = 9.8 Hz, 5-H₂), 6.8 - 7.8 (m, 2 C₆H₅). - MS (90°C); *m*/z (%): 358 (37) [M⁺], 270 (17) [C₁₅H₁₂NO₂S⁺], 239 (19), 212 (13) [C₁₄H₁₂S⁺, **15b**⁺], 211 (14), 208 (17), 198 (100) [C₁₃H₁₀S⁺, ¹³C 14.5/16.1, (³⁴S+¹³C₂) 5.4/5.7], 180 (20) [C₁₄H₁₂⁺], 165 (52) [C₁₃H₈⁺, fluorenyl⁺], 121 (21) [C₆H₅-C=S⁺], 118 (16), 105 (11) [C₈H₉⁺], 91 (8) [C₇H₇⁺], 77 (45) [C₆H₅⁺], 59 (28) [CH₃OC=O⁺]. - Anal. for C₁₈H₁₈N₂O₄S (358.4): calcd C 60.32, H 5.06, N 7.82; found C 60.63, H 4.92, N 7.88.

2,2-Diphenyl-1,3,4-thiadiazolidine-3,4-dicarboxy-(N-phenylimide) (23): Thiadiazoline 14b (2.99 mmol) and 3.29 mmol of 21 in 13 ml of THF were reacted at -45°C for 8 h; the ¹H NMR analysis (2-me-thylnaphthalene as standard) indicated 87% of 23. After removal of the solvent, trituration with diethyl ether afforded 961 mg (83%) of colorless crystals, mp 160-162°C (CHCl₃/ether). The CHCl₃ solution slowly turned light-blue on storing at daylight. - ¹H NMR: δ 4.80 (s, 5-H₂), 7.3 - 7.5 (m, 15 arom. H). - ¹³C NMR: δ 48.0 (t, C-5), 85.5 (s, C-2), 125.3, 128.1, 128.9, 129.1 (4 d, 15 arom. CH), 131.5, 137.6 (2 s, 3 arom. C_q), 150.2, 153.2 (2 C=O). - Anal. for C₂₂H₁₇N₃O₂S (387.4): calcd C 68.20, H 4.42, N 10.85, S 8.28; found C 68.05, H 4.23, N 10.81, S 8.22.

Fluorene-9-thione S-Methylide (15c)

Dimethyl Spiro[fluorene-9,2'-(1,3,4)-thiadiazolidine]-3',4'-dicarboxylate (16c): 14c ³³ (2.70 mmol), prepared in 8 ml of THF at -78°C, was treated with 501 mg (3.43 mmol) of 4 in 3 ml of THF at -45°C for 2 h. The ¹H NMR analysis (2-methylnaphthalene as weight standard) indicated 88% of 16c which crystallized from diethyl ether: 793 mg (82%) as colorless prisms, mp 169-171°C. - ¹H NMR: δ 3.32, 3.60 (2 s, 2 OCH₃), 4.86, 5.50 (AB, ²J = 10.6 Hz, 5'-H₂), 7.2 - 7.7 (m, 8 arom. H). - ¹³C NMR: δ 52.3 (t, C-5'), 52.9, 54.5 (2 q, 2 OCH₃), 80.1 (s, C-2'), 119.9, 120.2, 120.9, 125.1, 2 x 128.2, 129.0, 129.5 (8 d, 8 arom. CH), 138.2, 139.5, 143.5, 148.1 (4 s, 4 arom. C_q), 151.7, 157.8 (2 s, 2 C=O). - Anal. for C₁₈H₁₆N₂O₄S (356.4): calcd C 60.66, H 4.53, N 7.86, S 9.00; found C 60.57, H 4.72, N 7.62, S 8.89.

2,2,4,4-Tetramethyl-3-thioxocyclobutanone S-Methylide (15d)

Dimethyl 2,2,4,4-Tetramethyl-1-oxospiro[cyclobutane-3,2'-(1,3,4)-thiadiazolidine]-3',4'-dicarboxylate (16d): (a) Freshly recrystallized thiadiazoline 14d 34,35 (396 mg, 2.00 mmol) and 2.20 mmol of 4 in 4 ml of absol. THF were heated at 40°C for 8 h; the half-life for the thermolysis of 14d is 86 min.³⁶ The ¹H NMR analysis (*sym*-tetrachloroethane as standard) furnished 1.16 mmol (58%) of 16d (s δ 1.65, CH₃). PLC with CH₂Cl₂/acetone (20:1) afforded 337 mg of a colorless oil; the methanolic solution deposited 303 mg (48%) of 16d as colorless crystals, mp 110-112°C. - IR (KBr): $\tilde{\nu}$ 1262 cm⁻¹, 1390 st (C-O), 1488 st; 1700, 1757 st (ester C=O), 1785 (ketone C=O). - ¹H NMR: δ 1.27 (s, 2 CH₃), 1.41, 1.65 (2 s, 2 CH₃), 3.75 (s, 2 OCH₃), 4.38, 4.58 (AB, ²J = 7.5 Hz, 5'-H₂). - MS (60°C); *m/z* (%): 316 (2.4) [M⁺], 301 (0.8) [M⁺- CH₃], 257 (12) [M⁺- CO₂CH₃], 246 (100) [C₉H₁₄N₂O₄S⁺, M⁺- dimethylketene], 229 (61) [C₁₀H₁₅NO₃S⁺, M⁺- H₂C=N-CO₂CH₃], 187 (246 - CO₂CH₃), 143 (24), 127 (13), 102 (24). - Anal. for C₁₃H₂₀N₂O₅S (316.4): calcd C 49.35, H 6.37, N 8.86, S 10.14; found C 49.62, H 6.36, N 8.84, S 10.12.

(b) 2,4-Dinitrophenylhydrazone of 16d: 120 mg (0.38 mmol) and 1.0 mmol of 2,4-dinitrophenylhydrazine in 3 ml of ethanol and a drop of conc. sulfuric acid were refluxed for 10 h. During 20 h at r.t. 179 mg (95%) crystallized as a mixture (ratio ~ 1:1) of *syn-anti*-isomers, mp 174-178°C (dec) after recrystallization from CH₂Cl₂/pentane. - IR (KBr): $\hat{\nu}$ 1259 cm⁻¹, 1284, 1312 st (C-O), 1339 vst, 1592 st (NO₂), 1620 vst (C=N), 1710, 1758 st (C=O), 3333 (N-H). - ¹H NMR: δ 1.27, 1.46, 1.50, 2 x 1.62, 1.70, 1.77, 1.90 (8 s, 2 x 4 CH₃), 3.80, 3.82 (2 s, 2 OCH₃), 4.38/4.64 and 4.35/4.68 (2 AB, ²J ~ 8 Hz, 5'-H₂), 7.80 (d, ³J = 9.5 Hz, arom. 6-H), 8.26 (dd, J = 9.5, 2.8 Hz, arom. 5-H), 8.80 (d, ⁴J = 2.8 Hz, arom. 3-H), 11.00 (NH br, disappears with D₂O). - Anal. for C₁₉H₂₄N₆O₈S (496.5): calcd C 45.96, H 4.87, N 16.93, S 6.46; found C 45.92, H 4.92, N 16.87, S 6.47.

2,2,4,4-Tetramethyl-3-thioxocyclobutanone S-Ethylide (18d)

2',5'-Dihydro-2,2,4,4,5'-pentamethylspiro[cyclobutane-3,2'-(1,3,4)-thiadiazole]-1-one (17d): 20 ³⁷ (4.00 mmol) in 3 ml of diethyl ether at 0°C was reacted with ethereal diazoethane, until the yellow color remained for 1 min. The solvent was removed, and 17d crystallized from 20 ml of pentane at -78°C as colorless leaflets, mp 29-30°C; 17d is storable for months at -25°C. - IR (film): \tilde{v} 1024 cm⁻¹, 1454, 1463 m; 1789 st (C=O). - ¹H NMR: δ 1.22 (s, 2 CH₃), 1.25, 1.27 (2 s, 2 CH₃), 1.70 (d, ³J = 6.8 Hz, 5'-CH₃), 6.02 (q, ³J = 6.8 Hz, 5'-H). - MS (30°C); m/z (%): 212 (1.7) [M⁺], 197 (33) [M⁺- CH₃], 184 (27) [M⁺- N₂], 169 (12) [C₉H₁₃OS⁺, M⁺- N₂ - CH₃], 141 (13), 114 (83) [C₆H₁₀S⁺, 184 - dimethylketene], 96 (18), 86 (27), 81 (100) $[C_6H_9^+]$, 70 (23) $[C_4H_6O^+]$, 67 (44) $[C_5H_7^+]$. - Anal. for $C_{10}H_{16}N_2OS$ (212.3): calcd C 56.57, H 7.60, N 13.20, S 15.10; found C 56.53, H 7.53, N 13.23, S 14.83.

Dimethyl 2,2,4,4,5'-Pentamethyl-1-oxospiro[cyclobutane-3,2'-(1,3,4)-thiadiazolidine]-3',4'-dicarboxylate (19d): 17d (424 mg, 2.00 mmol) and 2.2 mmol of 7 in 4 ml of THF were reacted for 6 h at 45°C. The quantitat. ¹H NMR analysis indicated 63% of 19d (q δ 5.22). PLC with CH₂Cl₂/acetone (20:1) produced 312 mg (47%), mp 117-119°C (methanol). - IR (KBr): v 1266 cm⁻¹, 1387, 1448, 1456 st; 1703, 1752 st (ester C=O), 1788 st (ketone C=O). - ¹H NMR: δ 1.28 (s, 2 CH₃), 1.40, 1.62 (2 s, 2 CH₃), 1.52 (d, ³J = 6.2 Hz, 5'-CH₃), 3.77 (s, 2 OCH₃), 5.22 (q, ³J = 6.2 Hz), 5'-H). - MS (55°C); *m/z* (%): 330 (2) [M⁺], 315 (2.4) [M⁺- CH₃], 271 (11) [M⁺- CO₂CH₃], 260 (78) [C₁₀H₁₆N₂O₄S⁺, M⁺ - dimethylketene], 229 (100) [C₁₀H₁₅NO₃S⁺, M⁺- CH₃CH=N-CO₂CH₃, same fragment from 16d], 201 (85), 159 (28), 156 (31), 127 (35), 116 (19), 86 (24), 84 (30), 59 (70) [CH₃OC=O⁺]. - Anal. for C₁₄H₂₂N₂O₅S (330.4): calcd C 50.89, H 6.71, N 8.48, S 9.71; found C 51.11, H 6.82, N 8.57, S 9.92.

Acknowledgments

We express our thanks to the Fonds der Chemischen Industrie, Frankfurt, for supporting our research work. The Alexander von Humboldt Foundation provided X. L. and G. M. with stipends and deserves our thanks. We are indebted to Reinhard Seidl for the MS and thank Helmut Schulz and Magdalena Schwarz for the elemental analyses.

REFERENCES

Dedicated to Professor *Mieczyslaw Makosza*, Institute of Organic Chemistry, Polish Academy of Sciences, Warsaw, on the occasion of his sixty-fifth birthday.

- 1. 1,3-Dipolar Cycloadditions, 114; part 113 see ref. 5.
- Present addresses: Dr. X. Li, Avery Research Center, Pasadena, CA 91107, USA; Prof. G. Mloston, Institute of Organic and Applied Chemistry, University of Lodz, PL - 90-136 Lodz, Poland.
- 3. Huisgen, R.; Mloston, G., Polish J. Chem. 1999, 73, 635-644.
- 4. Mloston, G.; Huisgen, R.; Huber, H.; Stephenson, D. S., J. Heterocycl. Chem., in press.
- 5. Mloston, G.; Huisgen, R.; Polborn, K., Tetrahedron, in press.
- 6. Cookson, R. C.; Crab, T. A.; Frankel, J. J.; Hudec, J., Tetrahedron Suppl. 1966, 7, 355-390.
- Lynden-Bell, R. M., in *Progress in NMR Spectroscopy*; Emsley, J. W.; Feeney, J.; Sutcliffe, L. H., Eds.; Pergamon Press: Oxford, 1967; Chapter 4.
- 8. Shanan-Atidi, H.; Bar-Eli, K. H., J. Phys. Chem. 1970, 74, 961-963.
- Oki, M.; Iwamura, H.; Hayakawa, N., Bull. Chem. Soc. Jpn. 1964, 37, 1865-1870. Kurland, R. J.; Rubin, M. B.; Wise, W. B., J. Chem. Phys. 1964, 40, 2426-2427.
- 10. Kohata, K.; Fukuyama, T.; Kuchitsu, K., J. Phys. Chem. 1982, 86, 603-606.
- Vitkovskaya, N. M.; Dolgunicheva, O. Y.; Frolov, Y. L.; Keiko, U. V.; Voronkov, M. G., Dokl. Akad. Nauk SSSR 1977, 235, 843-845; Engl. Transl., 749-751.
- Excellent reviews: (a) Shvo, Y., Conformational Analysis of Hydrazines. In *The Chemistry of Hydrazo, Azo, and Azoxy Groups;* Patai, S., Ed.; John Wiley: New York, 1975; pp 1017-1095.
 (b) Nelsen, S. F., Hydrazine Stereodynamics. In *Acyclic Organonitrogen Stereodynamics*; Lambert, J. B.; Takeuchi, Y. Eds.; VCH: Weinheim, 1986; pp 89-121.

- 13. Ottersen, T., Acta Chem. Scand. 1974, A28, 1145-1149.
- 14. Jeffrey, G. A.; Ruble, J. R.; McMullan, R. K.; De Frees, D. J.; Pople, J. A., Acta Cryst. 1982, 38B, 1508-1513.
- 15. Ottersen, T., Acta Chem. Scand. 1978, A32, 127-131.
- 16. Dewar, M. J. S.; Jennings, W. B., J. Am. Chem. Soc. 1973, 95, 1562-1569.
- (a) Bishop, G. J.; Price, B. J.; Sutherland, I. O., J. Chem. Soc., Chem. Commun. 1967, 672-674.
 (b) Fletcher, J. R.; Sutherland, I. O., J. Chem. Soc., Chem. Commun. 1969, 706-708.
- (a) Breliere, J. C.; Lehn, J. M., J. Chem. Soc., Chem. Commun. 1965, 426-427. (b) Anderson, J. E.; Lehn, J. M., Tetrahedron 1968, 24, 123-135. (c) id., Tetrahedron 1968, 24, 137-149. (d) Wagner, J.; Wojnarowski, W.; Anderson, J. E.; Lehn, J. M., Tetrahedron 1969, 25, 657-676. (e) Lehn, J. M.; Wagner, J., Tetrahedron 1969, 25, 677-689.
- (a) Price, B. J.; Smallman, R. V.; Sutherland, I. O., J. Chem. Soc., Chem. Commun. 1966, 319-320. (b) Price, B. J., Sutherland, I. O.; Williamson, G. Q., Tetrahedron 1966, 22, 3477-3490.
- 20. Offereins, B.; Altona, C.; Romers, C., Acta Cryst. 1973, B29, 2098-2103.
- Electron diffraction: Dallinga, G.; Toneman, L. H., Rec. Trav. Chim. Pays-Bas 1968, 87, 785-804.
 Yokozeki, A.; Kuchitsu, K., Bull. Chem. Soc. Jpn. 1971, 44, 2356-2363.
- 22. Force field: Altona, C.; Sundaralingam, M., J. Am. Chem. Soc. 1970, 92, 1995-1999.
- 23. X-ray of anti-7-norbornenyl 4-bromobenzoate: Macdonald, A. C.; Trotter, J., Acta Cryst. 1965, 19, 456-463.
- 24. The authors are highly indebted to Professor Hendrik Zipse, Munich, for the AM1 calculation.
- Nelsen, S. F.; Blackstock, S. C.; Petillo, P. A.; Agmon, I.; Kaftory, M., J. Am. Chem. Soc. 1987, 109, 5724-5731.
- 26. Pitzer, K. S.; Donath, W. E., J. Am. Chem. Soc. 1959, 81, 3213-3218.
- 27. Krapcho, A. P.; Silvon, M. P.; Goldberg, I.; Jahngen, E. G. E., J. Org. Chem. 1974, 39, 860-861.
- 28. Katada, T.; Eguchi, S.; Sasaki, T., J. Chem. Soc., Perkin Trans. 1 1984, 2641-2647.
- Fisera, L.; Huisgen, R.; Kalwinsch, I.; Langhals, E.; Li, X.; Mloston, G.; Polborn, K.; Rapp, J.; Sicking, W.; Sustmann, R., Pure & Appl. Chem. 1996, 68, 789-798.
- (a) Kaftory, M.; Agmon, I., J. Am. Chem. Soc. 1984, 106, 7785-7793. (b) Agmon, I.; Kaftory, M.; Nelsen, S. F.; Blackstock, S. C., J. Am. Chem. Soc. 1986, 108, 4477-4484. (c) Nelsen, S. F.; Petillo, P. A.; Chang, H.; Frigo, T. B.; Dougherty, D. A.; Kaftory, M., J. Org. Chem. 1991, 56, 613-616.
- Egan, W.; Mislow, K., Princeton University, 1971. The table of X as a function of Δp was published by Sandstrom, J., in *Dynamic NMR Spectroscopy*, Academic Press: London-New York, 1982; pp 81-82.
- 32. Kalvinsch, I.; Li, X.; Gottstein, J.; Huisgen R., J. Am. Chem. Soc. 1981, 70, 7032-7033.
- 33. Huisgen, R.; Kalvinsch, I.; Li, X.; Mloston, G., Eur. J. Org. Chem., submitted.
- 34. Diebert, C. D., J. Org. Chem. 1970, 35, 1501-1505.
- 35. Huisgen, R.; Penelle, J.; Mloston, G.; Buyle Padias, A.; Hall, H.K., J. Am. Chem. Soc. 1992, 114, 266-274.
- 36. Measurements by E. Langhals, University of Munich, 1985.
- 37. Elam, U. E.; Davis, H. E., J. Org. Chem. 1967, 32, 1562-1565.