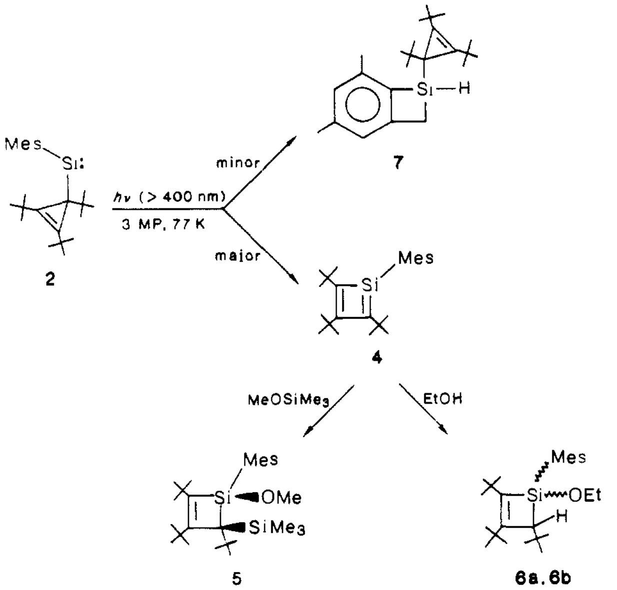
Scheme I. Generation and Trapping of Silacyclobutadiene **4**



Mes = mesityl: 2,4,6-trimethylphenyl

the silacyclobutadiene. The trapping experiments are summarized in Scheme I.

Also formed in each of the photolyses are smaller amounts (9%) of the benzosilacyclobutene **7**.[9] This compound likely arises from the photochemical insertion of the silylene **2** into a carbon–hydrogen bond of an ortho mesityl methyl group. An additional product from the ethanol trapping experiment is compound **3** (19%), the trapping product of the silylene **2** with ethanol.

The addition of methoxytrimethylsilane across the silicon-carbon double bond of the silacyclobutadiene is a completely stereospecific syn addition. This result is in good accord with reports by Jones on syn additions of this reagent (as well as methanol) to simpler acyclic silenes.[10] The formation of two diastereomers in our ethanol trapping experiments is explainable by photoisomerization of an initially formed diastereomer. Trapping of the silacyclobutadiene after only *one* cycle of photolysis gives only one diastereomer, **6a**, which is probably the syn addition product.

Further evidence for the photoisomerization of **6a** is found in the independent photolysis of either **6a** or **6b** in 3-MP glass at 77 K, followed by warming to room temperature. Photolysis of either pure diastereomer gives a photostationary mixture of **6a** and **6b** in approximately 1.2:1 ratio. The mechanism of photoisomerization is likely a concerted photochemical disrotatory ring opening to give a silabutadiene intermediate. A subsequent thermal conrotatory ring closure would be expected to produce the alternate stereoisomer. Interconversions of silacyclobutenes to silabutadienes have been suggested for several other systems.[11]

Finally, the silacyclobutadiene is not stable in solution despite the presence of sterically protecting groups. Annealing of a 3-MP glass containing **4** results in the loss of the silacyclobutadiene absorption bands and the generation of a stable dimeric product. The identity of this dimer is currently being investigated.

Acknowledgment. We thank the Tulane University Committee on Research and the Louisiana Board of Regents for support of this project.

Supplementary Material Available: Spectroscopic data for all new compounds, UV spectra, and tables of atomic coordinates with bond lengths and angles, positional parameters, anisotropic displacement parameters, and least-squares planes (16 pages); table of observed and calculated structure factors (34 pages). Ordering information is given on any current masthead page.

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[9] Also observed in each of the photolyses is another isomeric species with MW = 354, formed in approximately 5% yield. Attempts to purify this compound by preparative GC and HPLC have been currently unsuccessful.

[10] (a) Jones, P. R.; Bates, T. F.; Cowley, A. F.; Arif, A. M. *J. Am. Chem. Soc.* **1986**, *108*, 3123–3124. (b) Jones, P. R.; Bates, T. F. *J. Am. Chem. Soc.* **1987**, *109*, 913–914.

[11] (a) Valkovich, P. B.; Weber, W. P. *Tetrahedron. Lett.* **1975**, 2153–2154. (b) Block, E.; Revelle, L. K. *J. Am. Chem. Soc.* **1978**, *100*, 1630–1632. (c) Tzeng, D.; Fong, R. H.; Soysa, H. S. D.; Weber, W. P. *J. Organomet. Chem.* **1981**, *219*, 153–161. (d) Conlin, R.; Namavari, M. 8th International Organosilicon Symposium, St. Louis, MO, June 1987.

A Heteroaromatic Trimethylenemethane

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Trimethylenemethane and its two types of relatives, tetramethyleneethane and the non-Kekulé hydrocarbons, have been the subject of recent interest.[1-3] At the same time, the thiathiophthenes have also been of interest, particularly regarding unusual sulfur bonding.[4,5] In this communication we report on a novel sulfocarbon **1** which we found to be a trimethylenemethane embedded in a "pseudo-1,2-dithiolo-1,2-dithiole",[6] $(4n + 2)$ π-electron, milieu. A three-step synthesis of **1** is shown in Scheme I, below.[7]

Compound A was prepared as reported;[8] its conversion to B was possible only under basic conditions by suspension of A in aqueous base, followed by addition of a small amount of methanol to "wet" the solid.[6] The thionating reagent was prepared in situ from P_4S_{10} as described in the literature.[9] Thionation occurred cleanly only on the acid B and not the ester A.

The title compound forms small, air-stable orange (by transmission, purple by reflection) needles.[10] In solution the compound is orange [λ_{max}[CH_2Cl_2, nm (ε)] 251.5 (10 280), 285.4 (18 710), 305 sh (9890), 334.8 (13 960), 351.1 (12 990), 386.7 (7690), 415 sh (7950), 431.4 (9170) and 480 sh (2830)]. In the solid state, there are two bands at 350 and 440 as well as a shoulder at ca. 550 nm. The latter extends to the near-IR, indicative of solid-state intermolecular interactions. Since the usual spectroscopic structure determination techniques, particularly NMR,[11] were of little help, we resorted to X-ray crystallography. The structure presented some difficulty in its solution due to the relatively large unit cell[9] (16 molecules) with four distinct molecules per asymmetric unit

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[1] Dowd, P. *J. Am. Chem. Soc.* **1987**, *109*, 5284 and references therein.

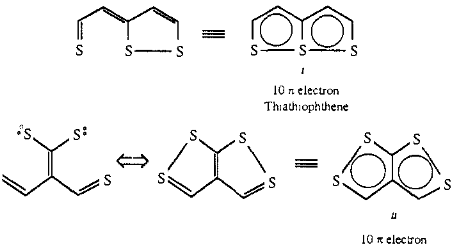
[2] Pranata, J.; Dogherty, D. A. *J. Am. Chem. Soc.* **1987**, *109*, 1621.

[3] Berson, J. E. *Acc. Chem. Res.* **1978**, *11*, 446.

[4] Hansen, L. K.; Hordvik, A. *Acta Chem. Scand.* **1973**, *27*, 411.

[5] Hansen, L. K.; Hordvik, A. *J. Chem. Soc., Chem. Commun.* **1974**, 800. Brown, J. P.; Gay, T. B. *J. Chem. Soc., Perkin Trans. 1* **1974**, 866.

[6] A referee pointed this out as follows where our molecule is of type ii:



i

10 π electron
Thiathiophthene

ii

10 π electron
"Dithiathienothiophene" or
"1,2-Dithiolo-1,2-dithiole"

[7] Experimental details are given in the Supplementary Material, see end of this article: Srdanov, G.; Rosenau, B.; Wellman, D.; Williams, K.; Cox, S. D.; Wudl, F. Report in preliminary form at the first International Heteroatom Conference, Kobe, Japan, July, 1987.

[8] Jensen, K. A.; Henriksen, L. *Acta Chem. Scand.* **1968**, *22*, 1107.

[9] Davy, H. *J. Chem. Soc., Chem. Commun.* **1982**, 457.

[10] $C_6H_4S_6$: $M = 268.48$; monoclinic space group $P2_1/n$; $a = 8.446$ (1) Å, $b = 26.530$ (3) Å, $c = 17.981$ (2) Å, $\beta = 101.24$ (5)°, $V = 3952$ (5) Å^3, $z = 16$; $\mu = 12.72$ cm^{-1}; $D_c = 1.80$ g cm^{-3}, $D_o = 1.79$ g cm^{-3}; $T = 298$ K; λ(Mo K_α) = 0.71069 Å; $R_w = 6.4\%$ for 2070 unique observed reflections.

[11] ^1H NMR ($CDCl_3$, δ rel to TMS) 3.5 s; ^{13}C NMR ($CDCl_3$, δ rel to TMS) 36.108, 140.129, 195.627, 211.489.

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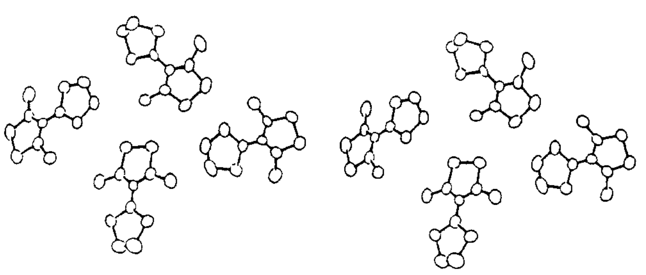
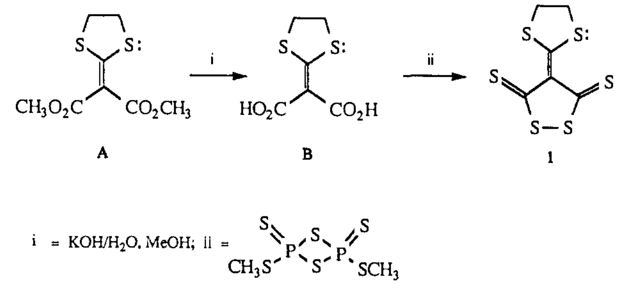
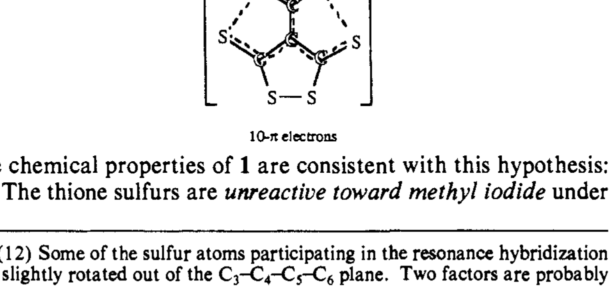


Figure 1. Stereoview of one asymmetric unit of the title compound's solid-state structure. Note the large "twist" of the ethylene bridge.

Scheme I



(AU, Figure 1) and the fact that the ethylene bridge of one of the molecules in the asymmetric unit was disordered. As can be seen in this figure and from Table I, all four central carbon atoms per molecule are coplanar, with the ethylene linkage showing a typical conformational twist and some of the sulfur atoms being rotated slightly out of the molecular plane. This twist is not the same for all molecules in the AU, and in one of the four this twisted ethylene is disordered. In Figure 2 we show the intramolecular bond distances and angles; these are an average of the four members of the AU. The most striking result is the practical *identity of bond length between the central carbon* (*C_4*) *and the three carbon atoms* (*C_3, C_5, and C_6*) *attached to it.* Furthermore, this bond length (1.42 Å) is the same as that found in another unusual thiathiophthene.[5] In addition, as shown in Figure 2, the C=S bond length is ~0.1 Å longer, and the C–S bonds are ~0.07 Å shorter than literature values. The S–S bond length is normal, whereas the intramolecular nonbonded S–S distance is ~0.7 Å *shorter than the sum of S van der Waals radii.* This observation implies that the molecule is a *heteroaromatic trimethylenemethane* with unusual bonding participation by the sulfur atoms:[12] Indeed, the chemical properties of 1 are consistent with this hypothesis: (i) The thione sulfurs are *unreactive toward methyl iodide* under conditions where normal thiones react (neat CH$_3$I at rom temperature or CH$_3$I in refluxing acetone). Trimethyloxonium hexafluorophosphate does methylate 1 in direct analogy to thiophene. (ii) Cyclic voltammetry (CV, CH$_2$Cl$_2$, Bu$_4$N$^+$ClO$_4$, 298 K) shows peaks at -0.73, 1.2 V vs. SCE, indicating that 1 is an unusually poor donor. The S-S bond reduction potential of -0.73 V is not unusual.[13] (iii) In agreement with the CV results, 1 does not produce a charge-transfer salt with TCNQ but only an unusual solvate[14] which exists in an alternate stacking motif with two donors and one acceptor in the same stack. The intramolecular interatomic parameters of the TCNQ molecule in this solid are, within experimental error, *indistinguishable* from those published for *neutral TCNQ*.[15,16]



10-π electrons

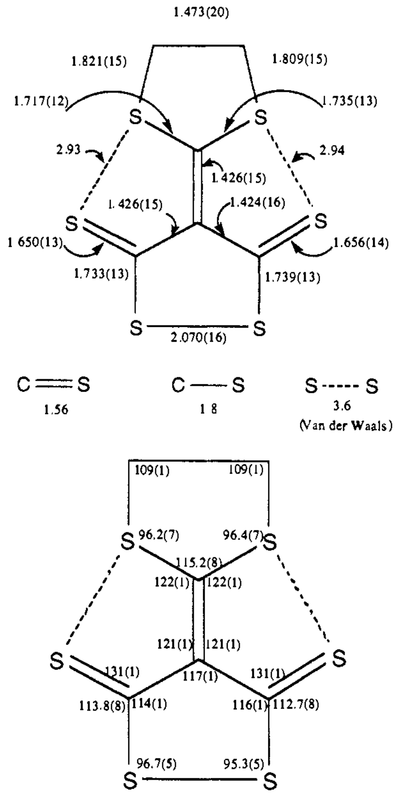
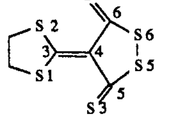


Figure 2. Schematic of the title compound describing bond lengths and angles. Accepted literature values for C=S, C–S, and van der Waals S–S distances (Adams, D. M. *Inorganic Solids*; John Wiley: 1974) are shown in the middle of the figure for comparison.

Table I. Deviations from a Least-Squares Plane[a,c] for One Molecule[b,c] in the Asymmetric Unit

atom	distance[a,c] Å	atom	distance[c,b] Å
S1	0.131	C3	-0.003
S2	-0.158	C4	0.007
S3	-0.044	C5	-0.002
S4	0.102	C6	-0.002
S5	-0.021		
S6	-0.010		

[a] Plane: $0.8609x - 0.05077y + 0.0336z = 0$. [b] Plane: $0.8525x - 0.5220y = 0.0274z = 0$. [c] Atom numbering is as follows:



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[12] Some of the sulfur atoms participating in the resonance hybridization are slightly rotated out of the C_3–C_4–C_5–C_6 plane. Two factors are probably operating: (1) the resonance hybridization between sulfur atoms which shortens the intramolecular, "nonbonded" S_1--S_3 (S_2--S_4) distance and (2) the Coulomb repulsion between σ-type lone pairs of the same sulfur atoms which lengthens this S--S distance. The latter could cause a twisting that displaces the sulfur atoms out of the plane defined by the four inner carbon atoms. *We thank a referee for pointing this out.*

[13] Horner, L.; Lund, H. In *Organic Electrochemistry*; 2nd ed.; Baizer, M. M.; Lund, H.; Eds.; Marcel Dekker, Inc: New York, 1983; Chapter 22.

[14] $C_{12}H_6N_2S_6$: $M = 370.48$; monoclinic space group $P2_1/c$; $a = 11.3768$ (9) Å, $b = 9.3251$ (5) Å, $c = 14.7562$ (13) Å; $\beta = 109.75$ (1)°, $V = 1473.4$ Å^3, $Z = 4$; $\mu = 8.795$ cm^{-1}; $D_c = 1.67$ g cm^{-3}; $D_o = 1.66$ g cm^{-3}; $T = 298$ K; λ(Mo Kα) = 0.71069 Å; $R_w = 7.2\%$ for 2425 unique observed reflections. Srdanov, G., unpublished.

In conclusion, we have discovered a molecule whose reactivity and molecular parameters led us to propose that it is a Hückel 10-π electron "bond-no-bond" resonance heteroaromatic singlet [no ESR signal (limit 1 spin/3 000 000 molecules) either in solution or in the solid state] trimethylenemethane outlined above.

In view of the fact that the disulfide linkage exhibits normal electrochemical properties one can expect that a large family of organic and transition-metal-derived compounds are preparable. We are actively pursuing this aspect as well as other chemistry[6] of this molecule.

Acknowledgment. We thank the National Science Foundation for support of this work through Solid State Chemistry, Materials Science Division Grant DMR-8514944.

Supplementary Material Available: Complete listings of bond lengths and bond angles and anisotropic temperature factors as well as positional parameters and synthetic details (7 pages). Ordering information is given on any current masthead page.

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(15) Long, R. R. E.; Sparks, R. A.; Trueblood, K. N. *J. Am. Chem. Soc.* **1965**, *18*, 932.

(16) The relevant parameters (italics, neutral TCNQ[13]) are as follows: C–N, 1.148 (6) versus *1.141*; exocyclic C=C, 1.372 (6) versus *1.374*; ring C–C, 1.446 (6) versus *1.446*; ring C–C, 1.455 (6) versus *1.450*; endocyclic C=C, 1.343 (6) versus *1.346*.

Molecular Recognition of Biologically Interesting Substrates: Synthesis of an Artificial Receptor for Barbiturates Employing Six Hydrogen Bonds[1]

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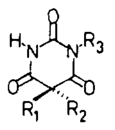
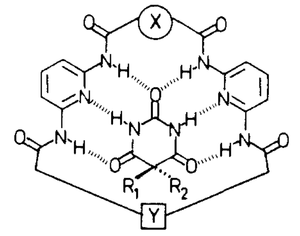
Received October 26, 1987

The role of hydrogen bonding in molecular recognition has been the focus of much recent attention.[3,4] In the design of artificial receptor molecules, the incorporation of several inwardly facing hydrogen bonding groups into a cleft[5] or cavity[6] of defined geometry should lead to strong and selective binding to those substrates showing complementary shape and H-bonding characteristics.[7] We have recently used this strategy to design receptors for thymine[8] involving three hydrogen bonds plus a stacking interaction.[9] In this paper we report the recognition and strong binding of barbiturate derivatives by a macrocyclic receptor containing *six* inwardly facing hydrogen bonds.

The families of drugs derived from barbituric acid **1a** are attractive targets for molecular recognition studies due to their widespread clinical use as sedatives[10] and anticonvulsants[11] and the range of derivatives available. Our approach to the recognition of barbiturates exploits the triple hydrogen bond complementarity between 2,6-diamidopyridines and imides.[9,12] Incorporation of two 2,6-diamidopyridine units into a macrocyclic structure (e.g., **2**) will permit the complexation of the six accessible hydrogen-bonding groups in 5,5-disubstituted barbiturates (e.g., barbital, **1b**). Suitable choice of spacer Y may allow a secondary recognition of the substituents in the 5,5-positions. Molecular modeling studies suggested that an isophthaloyl group (as X in **2**) would provide the necessary organization and rigidity to form the hexadentate binding site and that a diphenylmethane derivative (as Y in **2**) would accommodate the 5,5-ethyl groups of barbital.

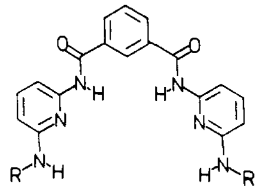


1a; $R_1 = R_2 = R_3 = H$
1b; $R_1 = R_2 = Et$, $R_3 = H$
1c; $R_1 = Et$, $R_2 = Ph$, $R_3 = H$
1d; $R_1 = Et$, $R_2 = Ph$, $R_3 = CH_3$
(racemic)

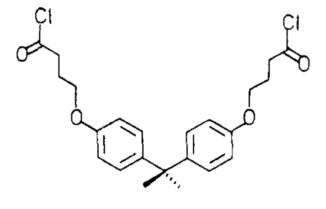


2

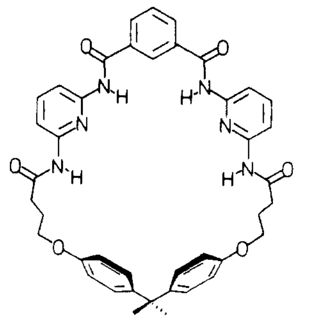
Reaction of isophthaloyl dichloride with an excess of 2,6-diaminopyridine (THF, Et_3N) gave diamine **3** in 79% yield. High dilution coupling of **3** and acid chloride **4** (THF, Et_3N) provided, after alumina chromatography (CH_2Cl_2, MeOH) and crystallization from THF–heptane, macrocyclic tetraamide **5** in 12% yield.[13]



3; R = H
6; R = $CO(CH_2)_2CH_3$



4



5

Complex formation between **5** or acycle **6** and various barbiturates was followed by ^1H NMR. For example, addition of 1 equiv of barbital **1b** to a $CDCl_3$ solution of **5** caused large downfield shifts of the host amide (1.65 and 1.63 ppm) and guest imide (4.38 ppm) proton resonances indicating the formation of

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(1) This paper is dedicated to the memory of Professor Iwao Tabushi.

(2) On leave from Chung-Ang University, Seoul, Korea.

(3) For a recent discussion, see: Fersht, A. R. *Trends Biochem. Sci.* **1987**, *12*, 301. Turner, D. H.; Sugimoto, N.; Kierzek, R.; Dreiker, S. D. *J. Am. Chem. Soc.* **1987**, *109*, 3783 and references therein.

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(9) Hamilton, A. D.; Van Engen, D. *J. Am. Chem. Soc.* **1987**, *109*, 5035. Hamilton, A. D.; Muehldorf, A., manuscript in preparation.

(10) Vida, J. A. In *Burger's Medicinal Chemistry*; Wolff, M. E., Ed.; Wiley-Interscience: New York, 1981; Part III, p 787.

(11) Isaacson, E. I.; Delgado, J. N. In *Burger's Medicinal Chemistry*; Wolff, M. E., Ed.; Wiley-Interscience: New York, 1981; Part III, p 829.

(12) Feibush, B.; Figueroa, A.; Charles, R.; Onan, K. D.; Feibush, P.; Karger, B. L. *J. Am. Chem. Soc.* **1986**, *108*, 3310.

(13) **5**: ^1H NMR ($CDCl_3$) 8.18 (2 H, br s, isophth CONH), 8.09 (3 H, m, pyr-3H, isophth-2H), 7.92 (6 H, m, pyr-5H, CH_2CONH, isophth-4, 6H), 7.76 (2 H, t, $J = 8$ Hz, pyr-4H), 7.64 (1 H, br t, isophth-5H), 7.02 (4 H, d, $J = 9$ Hz, phenol-3,5H), 6.71 (4 H, d, $J = 9$ Hz, phenol-2,6H), 4.03 (4 H, t, $J = 5.5$ Hz, CH_2O), 2.57 (4 H, m, CH_2CO), 2.19 (4 H, m, CH_2CH_2O), 1.54 (6H, s, CH_3); mass spectrum M^+ 712.3028 $C_{41}H_{40}N_6O_6$ requires 712.3009.

0002-7863/88/1510-1318$01.50/0