

ported the assignment of the UV spectra to oxacarbenes. The UV spectrum of **2** compares favorably with that predicted theoretically for hydroxymethylene (392 nm).³

In our previous investigations of methoxychloro- and phenoxychlorocarbenes we observed photochemical C-O cleavage leading to decarbonylation or rearrangement to the corresponding acid chlorides.^{5,6} Similarly, previous solution investigations of alkoxy-carbenes have observed only C-O cleavages.² In the case of **2**, in contrast, either of two α -cleavages apparently occur: C-O or C-C. Here, the weaker nature of the cyclopropyl bonds likely plays a role in making C-C cleavage competitive. Thermal fragmentations of this nature in cyclopropylmethylenes are, in fact, well known.¹² Although cyclopropylmethylenes (triplet) have been spectroscopically observed before,¹³ we believe this is the first exploration of their photochemistry. It is an open question whether or not the thermal and photochemical processes follow the same routes. The acetylene **5** has not been reported previously as a photoproduct of **1** either in solution^{2,7} or in the gas phase.¹⁴ We have found, however, that **5** is fairly unstable toward decomposition in solution and hence may have been lost in previous investigations. These questions as well as other aspects of oxymethylenes are being explored.

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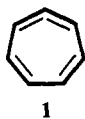
Cycloheptatrienylidene Singlet-Triplet Energetics: Theory Responds

Curtis L. Janssen and Henry F. Schaefer III*

*Department of Chemistry, University of California
Berkeley, California 94720*

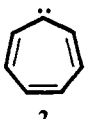
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Some time ago Radom, Vincent, and one of us (RSV)¹ predicted that the cyclic allene



1

lies energetically ~ 16 kcal/mol below the isomeric C_7H_6 carbene cycloheptatrienylidene stationary point



2

It was concluded that the observed² lowest energy structure (previously identified as **2**) in this sphere of the C_7H_6 potential energy hypersurface "is better named cycloheptatetraene". This prediction was confirmed 2 years later in Chapman's laboratory³ at UCLA. RSV also estimated that singlet cycloheptatrienylidene lies energetically below the triplet electronic state having a qualitatively similar planar stationary point geometry.¹

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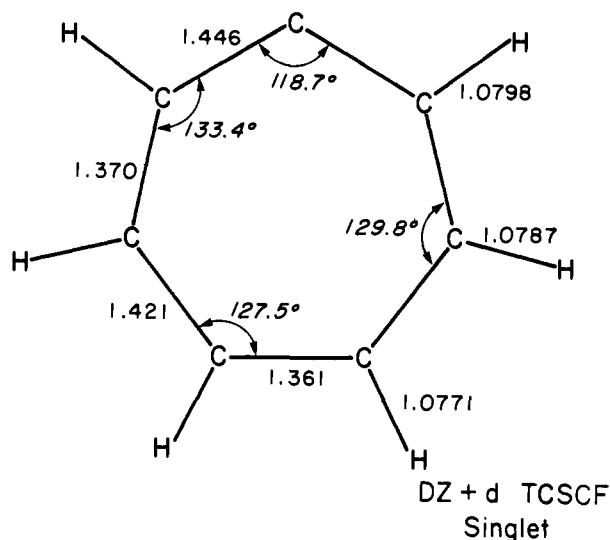


Figure 1. Theoretical structure for the lowest singlet state of planar cycloheptatrienylidene. A double ζ plus carbon d function (DZ + d) basis set was used in conjunction with two-configuration self-consistent-field theory (TCSCF).

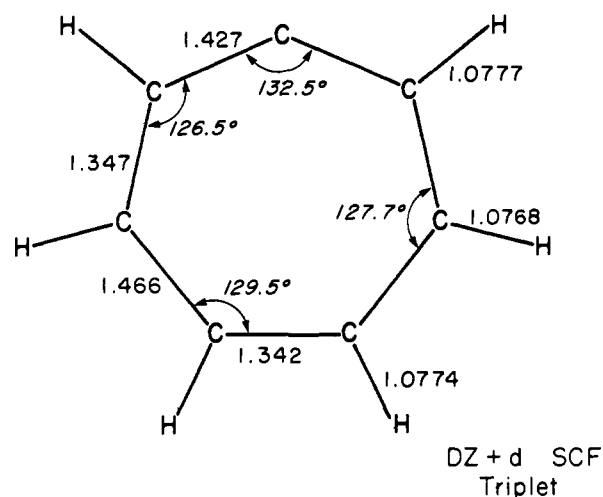


Figure 2. Ab initio equilibrium geometry for the lowest triplet state of planar cycloheptatrienylidene. All bond distances are in Å.

Very recently McMahon and Chapman⁴ have presented experimental results which appear to challenge the latter prediction from theory. Specifically, they report that cycloheptatrienylidene produces an intense ESR signal. McMahon and Chapman state⁴ that "observation of the ESR signal of cycloheptatrienylidene implies that the triplet state is either the ground state or within several calories per mole of the ground state". They then conclude that "the triplet ground state of cycloheptatrienylidene necessitates a re-evaluation of both qualitative arguments... and the calculations".

An independent experimental communication (appearing a few months later) by Kuzaj, Lüerssen, and Wentrup⁵ states less dogmatically that "one intriguing possibility is that (cycloheptatrienylidene) has a triplet ground state", again based on ESR observations. It is significant that the EPR parameters D and E assigned by Chapman⁴ to **2** are rather different from those assigned by Wentrup⁵ to the same molecule. It would appear that one of the ESR assignments is incorrect.

In this communication we confirm that the theoretical predictions of RSV are correct and suggest that they are indeed consistent with the very recent experiments of McMahon and

(4) McMahon, R. J.; Chapman, O. L. *J. Am. Chem. Soc.* **1986**, 108, 1713.

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Table I. Energetic Predictions for Singlet and Triplet Cycloheptatrienyldene^a

basis set	wave function	total energy (hartrees)	rel energy (kcal/mol)
minimum	triplet SCF	-265.14735	-15.3
minimum	singlet SCF	-265.11089	7.6
minimum	singlet TCSCF	-265.12294	0.0
DZ	triplet SCF	-268.36388	-4.7
DZ	singlet SCF	-268.34813	5.2
DZ	singlet TCSCF	-268.35634	0.0
DZ + d	triplet SCF	-268.46865	1.8
DZ + d	singlet SCF	-268.45880	8.0
DZ + d	singlet TCSCF	-268.47152	0.0

^aEach total energy reported here corresponds to a completely optimized molecular structure of C₇H₆.

Chapman⁴ and of Kuzaj, Lüerssen, and Wentrup.⁵

The earlier molecular structure optimizations of RSV¹ could be criticized in that they were carried out at the minimum basis set (MBS) self-consistent-field (SCF) level of theory. In the present research both structures were optimized by using a much larger double ζ plus d function (DZ + d) basis set,⁶ designated C(9s5p1d/4s2p1d), H(4s/2s). The triplet state was described at the single-configuration SCF level of theory and the singlet state at the two-configuration (TC) SCF level of theory.⁷

The predicted structures of singlet and triplet cycloheptatrienyldene are seen in Figures 1 and 2. Differences with respect to the minimum basis (MBS) structures of RSV¹ are substantive but not qualitative in nature. For example, for the triplet structure, the DZ + d SCF C-C distances to the carbene carbon are 1.427 Å, or 0.033 Å less than the earlier MBS SCF prediction. At an intermediate level of theory, DZ SCF for the triplet state and DZ TCSCF for the singlet, we find in the present research that both structures are predicted to be genuine minima—that is, all 3 (13) - 6 = 33 vibrational frequencies are real.

The theoretical energetic predictions are summarized in Table I. At the highest structurally optimized level of theory presented there the singlet energy falls below the triplet by 1.8 kcal/mol. For CH₂, the simplest carbene, the analogous DZ + d SCF/TCSCF level of theory predicts a singlet-triplet separation of 12.3 kcal,⁸ while the experimental value (in accord with the highest levels of theory) is $\Delta E(S-T) = 9.1$ kcal.⁹ If the analogy with methylene is valid, one would expect the exact value of $\Delta E(S-T)$ to be about 5 kcal for cycloheptatrienyldene.

The above supposition is confirmed by higher level theoretical studies. For example when the basis set for the carbene carbon is extended to C(9s5p2d/7s4p2d), total energies of -268.47747 (singlet TCSCF) and -268.47190 hartrees (triplet SCF) are obtained, yielding a singlet-triplet splitting of 3.5 kcal/mol. Going back to the original DZ + d basis set, configuration interaction (CI) wave functions including all single and double excitations were also determined. The corresponding energies are -269.17465 (singlet two-reference CISD) and -269.17015 (triplet CISD), yielding a singlet-triplet splitting of 2.8 kcal. Adding the two corrections (1.7 kcal for basis set, 1.0 kcal for correlation effects) to the results in Table I yields $\Delta E(S-T) = 4.5$ kcal/mol.

Given the clear theoretical prediction that cycloheptatrienyldene has a singlet ground state, why is an EPR spectrum observed in the laboratory? The simplest explanation would appear to be that the triplet state is lower in energy than the singlet at the former's equilibrium geometry. This hypothesis has been confirmed at the DZ + d triplet SCF/singlet TCSCF level of theory. At the

triplet equilibrium geometry, the singlet energy lies 6.7 kcal/mol higher. Thus, although the singlet state is indeed the true planar ground state (as predicted earlier¹), the triplet state minimum is well separated geometrically (the singlet and triplet C-carbene C-C angles differ by 13.8°; analogous singlet and triplet bond distances differ by as much as 0.045 Å) and has a relatively long lifetime with respect to intersystem crossing.

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Structure of FK506: A Novel Immunosuppressant Isolated from *Streptomyces*

Hirokazu Tanaka,* Akio Kuroda, Hiroshi Marusawa, Hiroshi Hatanaka, Toru Kino, Toshio Goto, and Masashi Hashimoto

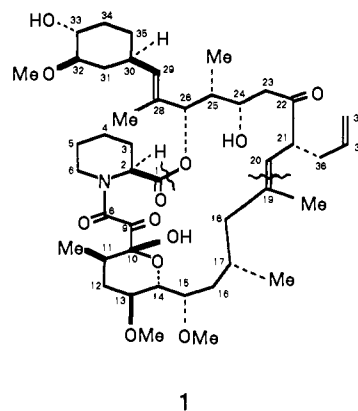
Exploratory Research Laboratories
Fujisawa Pharmaceutical Co., Ltd.
5-2-3 Tokodai, Toyosato-machi, Tsukuba-gun
Ibaraki 300-26, Japan

Tooru Taga

Faculty of Pharmaceutical Sciences
Kyoto University, Yoshida Shimoadachi
Sakyo-ku, Kyoto 606, Japan
Received March 19, 1987

Considerable attention has recently been focused on the immunosuppressants represented by ciclosporins¹ because of their usefulness in bone marrow and organ transplantations. In the course of search for such immunosuppressive agents in our laboratories, FK506 (**1**), a novel 23-membered macrolide lactone, was isolated from *Streptomyces tsukubaensis* no. 9993. Herein we report the structural elucidation of this natural product.

FK506 (**1**) was isolated as colorless prisms from MeCN;² C₄₄H₆₉NO₁₂ (SIMS and elemental analysis³); mp 127-129 °C; [α]_D -84.4° (c 1.02, CHCl₃). The IR spectrum (CHCl₃) showed the presence of hydroxy groups (3700, 3600, 3550 cm⁻¹), carbonyl groups (1750, 1730, 1710 cm⁻¹), and an amide group (1650 cm⁻¹). The ¹³C NMR spectrum (CDCl₃) revealed that **1** exists as an



equilibrium mixture of two isomers in solution (ca. 3:1 in CDCl₃). A detailed analysis of the spectrum⁴ with the aid of the DEPT technique revealed all the carbon signals which are assignable to

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(3) SIMS, *m/z* 804 (M + 1); elemental analysis. Anal. Calcd for C₄₄H₆₉NO₁₂·H₂O: C, 64.29; H, 8.71; N, 1.70. Found: C, 64.20; H, 8.86; N, 1.72.

(4) Spectral data for FK506 (**1**) and its degradation products (**2**, **3**, **6**, **7**, and **9**) are given in the Supplementary Material.