C-1 Stereochemistry of the Di-π-methane Rearrangement. Mechanistic and Exploratory Organic Photochemistry[1,2]

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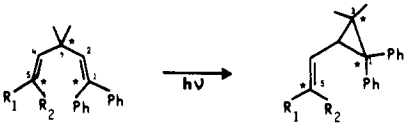
Abstract: The di-π-methane rearrangement of the 3,3,5-trimethyl-1-phenyl-1,4-hexadiene stereoisomers was studied in order to determine the stereochemical course of the reaction at C-1. *cis*- and *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene were synthesized and subjected to direct and sensitized irradiations. It was observed that direct photolysis of the cis hexadiene reactant led to *cis*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane as the major product. Similar photolysis of the trans hexadiene afforded the trans vinylcyclopropane. Additionally, a 2 + 2 cycloaddition product was obtained from both reactants and cis–trans isomerization was observed as a competing process. Quantum yields were determined for all processes. In the case of sensitized runs, it was found that the triplet of hexadiene reactants merely underwent cis–trans isomerization and gave no di-π-methane rearrangement. The results are explicable in terms of an excited singlet Möbius orbital array and are not understood merely in terms of least motion.

The di-π-methane rearrangement has proven to be one of the most ubiquitous of photochemical rearrangements.[3] Thus a complete understanding of the reaction is particularly important. Accordingly, we have been especially interested in the reaction stereochemistry. Previously, we have shown[4] that configuration at C-5 of the cis and trans isomers of 1,1-diphenyl-3,3-dimethyl-1,4-hexadiene (**1a** and **1b**) is retained during rearrangement to the vinylcyclopropane (**2a** and **2b**); note eq 1.

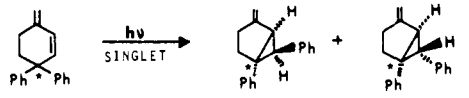


(1)

1a, R_1 = H; R_2 = Me 2a, R_1 = H; R_2 = Me
b, R_1 = Me; R_2 = H b, R_1 = Me; R_2 = H

*Centers of stereochemistry

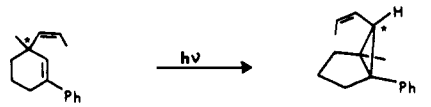
Additionally there is stereochemistry to be found at carbon atoms 3 and 1 in the reaction. Tentative evidence available suggests that the configuration at C-3 (*i.e.*, the methane carbon) is inverted in the di-π-methane rearrangement. One example is that of 1-methylene-4,4-diphenyl-2-cyclohexene (**3**) which rearranges *via* the singlet with a kinetic preference for the trans product (*i.e.*, **4a**).[5] Careful inspection reveals that the configuration at the methane carbon, labeled with an asterisk in eq 2, is inverted as the phenyl migrates from this center to the adjacent diene system to give the major product **4a**.



(2)

3 4a (major) 4b (minor)

Another example is found in the elegant work of Mariano[6] shown in eq 3. Again the methane carbon is inverted.



(3)

5 6

*labels the methane carbon

All of the examples considered above involve reactions of the singlet excited state and triplet-state examples are presently not considered.[7]

With the stereochemistry at one of the three stereochemical centers established (*i.e.*, C-5) and that at the second center (*i.e.*, C-3) tentatively revealed, we proceeded with interest to investigate the stereochemical outcome at the last center, namely C-1.

The system chosen for investigation was 3,3,5-trimethyl-1-phenyl-1,4-hexadiene (**7**). This choice was dictated by mechanistic considerations which promised regioselectivity in which the C-1 phenyl group would appear cis or trans to the vinyl group on the three ring of the photoproduct (*vide infra*).

Synthesis of Photochemical Reactants and Anticipated Photoproducts. A convenient starting material for the synthesis of the di-π-methanes **7a** and **7b** was 2,2,4-trimethyl-3-pentenal[8] (**8**). As depicted in eq 4, this aldehyde reacted with benzylidenetriphenylphosphorane to give a mixture of *cis*- and *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene (**7a** and **7b**, respectively) in which the cis stereoisomer predominated 3:2. In contrast,

(1) Paper LXXXIV of the series. For the previous paper on mechanistic and exploratory organic photochemistry, note H. E. Zimmerman, D. P. Werthemann, and K. S. Kamm, *J. Amer. Chem. Soc.*, **96**, 439 (1974).

(2) See H. E. Zimmerman, P. Baeckstrom, T. Johnson, and D. W. Kurtz, *J. Amer. Chem. Soc.*, **94**, 5504 (1972), for a preliminary report of the present research.

(3) S. S. Hixson, P. S. Mariano, and H. E. Zimmerman, *Chem. Rev.*, **73**, 531 (1973).

(4) H. E. Zimmerman and A. C. Pratt, *J. Amer. Chem. Soc.*, **92**, 6267 (1970).

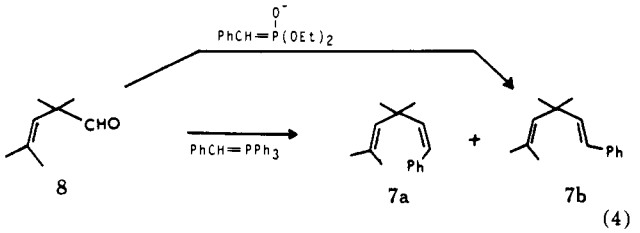
(5) H. E. Zimmerman and G. A. Samuelson, *J. Amer. Chem. Soc.*, **91**, 5307 (1969).

(6) P. S. Mariano and J. K. Ko, *J. Amer. Chem. Soc.*, **94**, 1766 (1972).

(7) One intriguing example which is not discussed above does proceed with retention of configuration at the methane carbon. In this case by P. S. Mariano, R. B. Steittle, and J. K. Ko (Contributed Papers, 4th IUPAC International Symposium on Photochemistry, Baden-Baden, Germany, 1972, p 156), molecular geometry enforced the observed stereochemistry.

(8) (a) M. Julia and M. Baillarge, *Bull. Soc. Chim. Fr.*, 734 (1966); (b) R. H. Hasek, R. D. Clark, and J. H. Chaudet, *J. Org. Chem.*, **26**, 3130 (1961).

the same aldehyde reacted with diethyl benzylphosphonate conjugate base to afford exclusively the trans hexadiene **7b**.



(4)

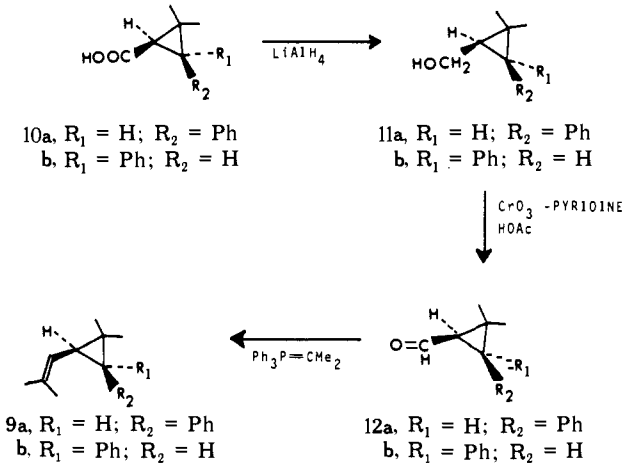
The configurations of these two compounds were based on spectral data and on the mode of formation. Thus, the infrared spectrum of the trans hexadiene **7b** exhibited a strong 10.36-μ band characteristic[9] of *trans*-1,2-disubstituted alkenes. This peak was absent, as expected, in the cis hexadiene **7a**.

The nmr also was indicative. The cis isomer **7a** afforded an AB quartet with τ 3.67 and 4.34 chemical shifts and a J = 12.8 Hz coupling constant. The trans isomer **7b**, in contrast, revealed a sharp singlet at τ 3.80. This type of behavior has been reported[10] for other cis and trans stereoisomers of the general structure PhCH=CHC(Me)$_2$R. (Not for cases without the central *gem*-dimethyl).

Finally, the configurational assignment is supported by the expectation[11] that the thermodynamically more stable isomer would result from the phosphonate Wittig approach while use of the phosphorane would give an excess of the less stable product.

It was hoped that the photochemistry of **7a** and **7b** would afford the stereoisomeric 3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropanes (**9a** and **9b**). Consequently, independent syntheses for these compounds were desired. A convenient starting point was the known[12] *cis*- and *trans*-3,3-dimethyl-2-phenylcyclopropanecarboxylic acids (**10a** and **10b**, respectively). Each of these was converted with lithium aluminum hydride to the corresponding carbinol (**11a** and **11b**); note Chart I. The carbinols **11a** and **11b** were then oxidized with chromium trioxide–pyridine in acetic acid to the aldehydes **12a** and **12b**. Finally, these were treated with isopropylidenetriphenylphosphorane to afford the desired vinylcyclopropanes **9a** and **9b**. The synthesis is summarized in Chart I and detailed in the Experimental Section.

Chart I. Synthesis of the Stereoisomeric 3,3-Dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropanes



10a, R_1 = H; R_2 = Ph
b, R_1 = Ph; R_2 = H

11a, R_1 = H; R_2 = Ph
b, R_1 = Ph; R_2 = H

9a, R_1 = H; R_2 = Ph
b, R_1 = Ph; R_2 = H

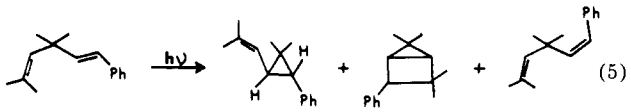
12a, R_1 = H; R_2 = Ph
b, R_1 = Ph; R_2 = H

Exploratory Photochemical Efforts. With the desired di-π-methane reactants **7a** and **7b**, as well as the anticipated vinylcyclopropane products **9a** and **9b**, in hand, attention was turned to photochemical aspects of the research. It was found that irradiation of *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene (**7b**) in *tert*-butyl alcohol using a 450-W immersion apparatus and Corex filter led to complete consumption of reactant in 1.5 hr. The major product isolated by column chromatography proved to be *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane (**9b**). Additionally, as a lesser product there was obtained an isomer whose nmr spectrum proved identical with that reported by Hammond for one stereoisomer of 2,2,5,5-tetramethyl-3-phenylbicyclo[2.1.0]pentane (**13**).[13] Also, some cis isomer of di-π-methane reactant was obtained.

The photolysis of *cis*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene (**7a**) proceeded similarly except that rather extensive cis–trans isomerization of reactant was evident. Thus there were isolated small amounts of recovered starting cis hexadiene **7a**, trans hexadiene **7b**, cis and trans vinylcyclopropanes **9a** and **9b**, together with a smaller quantity of housane **13**. The observed photochemistry is summarized in eq 5 and 6.

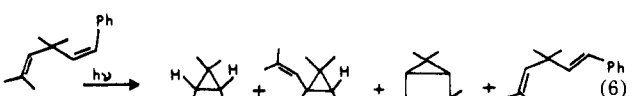
Quantitative Studies. Determination of Reaction Efficiency, Stereochemistry, and Multiplicity. It was obvious from the exploratory runs that cis–trans isomerization of the di-π-methane reactants was a complication in observing the stereochemical course of the reaction. Thus runs to much lower conversion were needed along with a sensitive method of product analysis. Presently, vapor phase chromatography proved ideal for the latter requirement.

It was observed that at lower conversions it was possible to determine the kinetic distribution of products. These results, in the form of quantum yield determinations, are gathered under eq 5 and 6. The results given are the averages of several runs.



(5)

	7b	9b	13	7a
direct:				
	ϕ = 0.212	ϕ = 0.098	ϕ = 0.077	ϕ = 0.037
sensitized:				
	ϕ = 0.129	ϕ = 0.000	ϕ = 0.000	ϕ = 0.109



(6)

	9a	9b	13	7b
direct:				
	ϕ = 0.109	ϕ = 0.050	ϕ = 0.013	ϕ = 0.005	ϕ = 0.041
sensitized:				
	ϕ = 0.139	ϕ = 0.000	ϕ = 0.000	ϕ = 0.000	ϕ = 0.090

Although we see that only trans vinylcyclopropane

(9) K. Nakanishi, "Infrared Absorption Spectroscopy," Holden-Day, San Francisco, Calif., 1962, p 25.
(10) D. Seyferth and G. Singh, *J. Amer. Chem. Soc.*, **87**, 4156 (1965).
(11) W. S. Wadsworth and W. D. Emmons, *J. Amer. Chem. Soc.*, **83**, 1732 (1961).
(12) (a) F. Sorm and J. Farkas, *Chem. Listy*, **52**, 688 (1958). (b) Configurations were established by D. J. Patel, M. E. H. Howden, and J. D. Roberts, *J. Amer. Chem. Soc.*, **85**, 3218 (1963).
(13) H. Kristinsson and G. S. Hammond, *J. Amer. Chem. Soc.*, **89**, 5970 (1967).

product **9b** results from the photolysis of trans di-π-methane reactant **7b**, some lack of stereospecificity is observed in runs starting with cis di-π-methane **7a**. Although photolyses were run to as low as 3% conversion, the relatively high quantum yield for reactant cis–trans isomerization (note eq 6) results in trans di-π-methane which can absorb light, react, and lead to the trans vinylcyclopropane product **9b** observed. This is a consequence of the sevenfold greater extinction coefficient and twofold greater reaction efficiency of the trans di-π-methane relative to the cis isomer.

It is seen then that the reaction is either totally or largely stereospecific.

A final point derives from these runs, and this is the multiplicity of the excited state leading to the di-π-methane products **9a** and **9b**. We see that in the benzophenone sensitized runs only cis–trans isomerization of hexadiene reactant was observed. This characterizes the photochemical behavior of the triplet excited state and requires that the vinylcyclopropane products encountered in the direct irradiations must come from another electronic excited state, namely the singlet.

Interpretative Discussion of the Results. A number of aspects require discussion: the regiospecificity, the reaction multiplicity, and the stereochemistry.

It was noted at the outset that the di-π-methane reactant **7** was specifically designed to give products with the phenyl group on C-1 of the cyclopropane ring of the product. This was based on analogy with previously observed regiospecificity. Thus, in the present instance the usual valence bond representation for the reaction mechanism leads to an excited cyclopropyldicarbinyl diradical **14**; note Chart II. There are, *a priori*, two pathways A and B involving scission of the three-membered ring. Previously we have noted that the reaction proceeds in such a manner that maximum free valence stabilization results.[14] In the present instance it is not perfectly predictable which pathway maintains maximum delocalization during the ring-opening step of the reaction. The two odd electrons shown in structure **14** really are used as a formalism. The rearranging cyclopropyldicarbinyl diradical is believed to be electronically excited (*i.e.*, in its S_1 state) and evidence has been cited that the dominant nature of the free valences is ionic (*i.e.*, an admixture of + − and − + contributions).[15] Thus, three-ring opening of structure **14** should occur in such a way that there is maximum stabilization of the free valences at C-1 *vs.* C-5 as the transformation proceeds either to species **15** or **16**. *A priori*, it is not apparent whether the phenyl group at C-1 or the two methyl groups at C-5 will lead to greater delocalization. However, with anything other than a positive center single phenyl substitution should lower energy more than double methyl substitution.[16] Our earlier studies have shown two phenyls to be more stabilizing than either one[5] or two[14a] methyl groups.

Consequently, it was of great interest to find that path A and not path B was utilized in the rearrangement. We can conclude that the nature of the free valences in cyclopropyldicarbinyl diradical species **14** is such that single phenyl substitution is more effective than double methyl substitution.

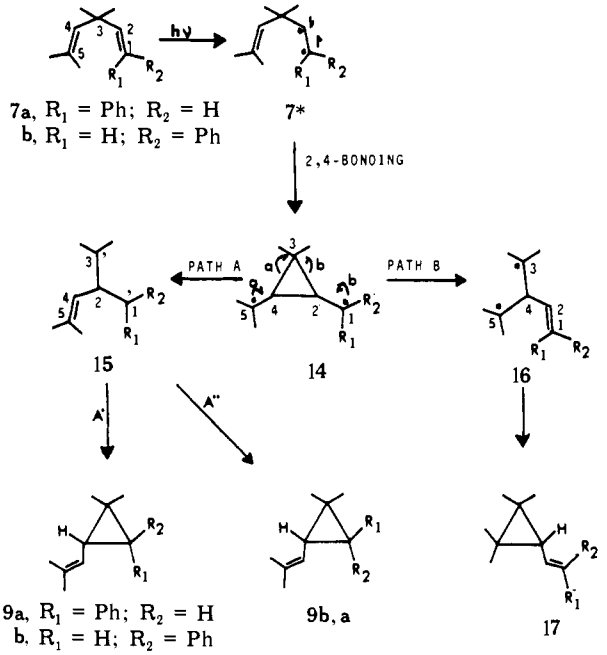
Another result requiring consideration is the reaction multiplicity. This point is not really separable from the matter of reaction stereochemistry and the two are thus discussed together.

That the reaction proceeds *via* the singlet excited state is apparent from the lack of di-π-methane rearrangement when the triplet is generated independently by benzophenone sensitization. The occurrence of cis–trans isomerization of di-π-methane reactants **7a** and **7b** confirms that energy was indeed being transferred under the conditions utilized.

However, an additional conclusion involves both multiplicity and stereochemistry. The stereochemistry of the singlet reaction suggests that species **14** is not as simple as one might think from its resonance structure formulation. For example, one might be concerned that rotation about bond 1–2 would lose stereochemistry. But stereochemistry is not lost, as noted in the results sections. Stereospecificity could nevertheless result from biradical species **14** if the rate of path A opening were much more rapid than free rotation.

Another piece of evidence indicating that species **14** is not a simple ground-state species is its rearrangement to give vinylcyclopropane product. It is clear from the literature[17] that ground-state cyclopropyldicarbinyl diradical species and their relatives (*vide infra*) react by

Chart II. Available Reaction Pathways



(14) (a) H. E. Zimmerman and A. C. Pratt, *J. Amer. Chem. Soc.*, **92**, 6259 (1970); (b) H. E. Zimmerman and A. A. Baum, *ibid.*, **93**, 3646 (1971); (c) see also ref 4.

(15) H. E. Zimmerman, D. P. Werthemann, and K. S. Kamm, *J. Amer. Chem. Soc.*, **95**, 4606 (1973).

(16) (a) The behavior of anionic centers in ground-state chemistry tells us that methyl substitution is destabilizing while phenyl is stabilizing. For cationic carbon, both phenyl and methyl stabilize[16b] but the latter does so more weakly. Thus, for intermediate charge densities the one phenyl might be selected as stabilizing more effectively than two methyls. (b) Winstein's rule of thumb suggests that two methyls are equivalent to one phenyl in stabilizing a cationic center; note S. Winstein, B. K. Morse, E. Grunwald, K. C. Schreiber, and J. Corse, *J. Amer. Chem. Soc.*, **74**, 1113 (1952).

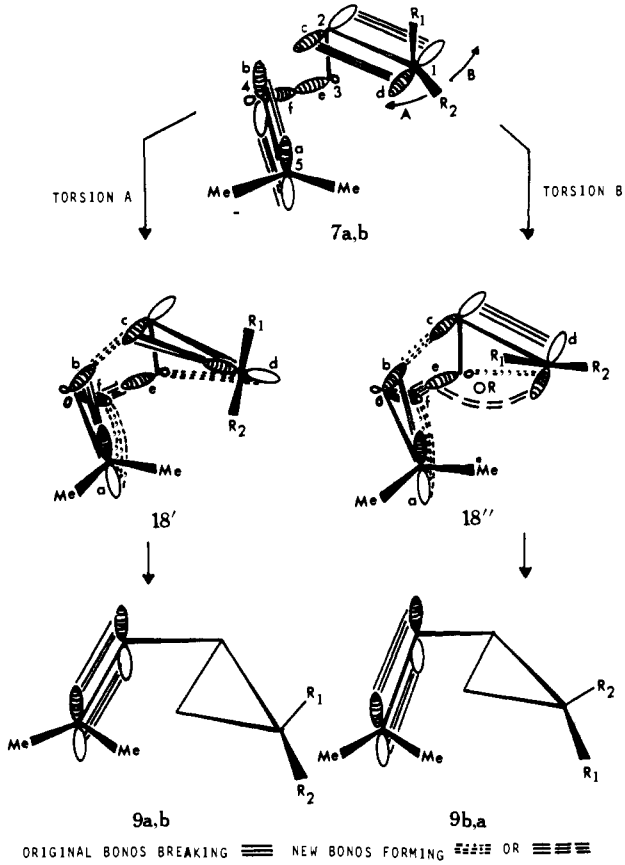
(17) (a) A model for ground-state cyclopropyldicarbinyl diradicals is found in the cyclic transition state of azo compounds which would lead to this species if the central three-ring σ bond did not open as is invariably observed thermally. (b) Note J. A. Berson and S. S. Olin, *J. Amer. Chem. Soc.*, **92**, 1986 (1970); B. M. Trost and R. M. Cory, *ibid.*, **93**, 5573 (1971) as leading references.

central σ-bond fission to give 1,4-dienes. Presently, such a reaction would lead diradical **14** back to the di-π-methane reactant **7**. While this process may well account reasonably for the less than unity quantum efficiency, and has indeed been suggested[15] as a mode of radiationless decay, the relative efficiency of the di-π-methane rearrangement in general is in contrast with the thermal chemistry and requires that the ground-state diradical (S_0) only affords 1,4-diene while the excited singlet (S_1) rearranges to vinylcyclopropane. Also, the ground-state diradical (S_0) may have sufficient lifetime to undergo free rotation and thus lead to the heavy stereoisomerization of reactant hexadiene as observed.

We note that the triplet excited state does not afford vinylcyclopropane product but does lead to cis–trans isomerization of diene reactant. This suggests that the triplet counterpart of diradical **14** is formed but cannot proceed further along the di-π-methane reaction coordinate. This then allows the diradical to undergo conformational equilibration and eventually decay to its ground-state counterpart which, in turn, reverts to stereoisomerized hexadiene **7a** plus **7b**.

The most intriguing feature of the results still remains and this is the nature of the stereospecificity of the reaction. The stereochemical course of the reaction is shown in Chart III, where for convenience the

Chart III. Basis Orbital Array and Reaction Stereochemistry



syn–syn geometry of the reacting species, in which the two π bonds and C-3 are in a U-shaped conformation, is drawn. The stereochemical reasoning is independent of what conformation is assumed for the reacting species.

Chart III shows that a clockwise twist about bond 1–2 (labeled torsion A) converts the cis reactant **7a** into cis product, *i.e.*, **9a**, and trans reactant **7b** into trans product **9b**. This is the reaction course observed experimentally. The alternative stereochemistry results from torsion B in which there is a counterclockwise twist about bond 1–2. This reaction course would lead cis reactant **7a** to trans product **9b** and trans reactant **7b** to cis product **9a**. But this reaction course is not obtained experimentally.

Visualization of Chart III leads to the conclusion that torsions A and B require closely equal angular twists in opposite directions, and therefore least motion will not rationalize the reaction stereochemistry. This striking result means that the reaction stereochemistry is being controlled by electronic factors.

We note that at half-reaction both species, **18′** and **18″**, consist of cyclic arrays of six orbitals. Array **18′** has one sign inversion between two adjacent orbitals and therefore is of the Möbius variety.[18] There are six delocalized electrons in the array (two from each of the original π bonds and two from the 3,4 σ bond). With six electrons, a reaction with a Möbius basis orbital array is ground-state forbidden but excited-state allowed. In contrast, array **18″** suffers the disadvantage of having to proceed with retention of configuration at C-3 in order to be photochemically allowed. Thus, with overlap ≡≡≡ (note **18″** in Chart III) the array is Möbius. Also, noting that only one lobe of the orbital at C-3 is used, we see that the mechanism leads to retention of configuration at this carbon. Previously, we have noted that tentative indications suggest inversion of the C-3 configuration is preferred in the di-π-methane rearrangement. With the alternative overlap ≡≡≡ C-3 is inverted using both lobes of the orbital at this carbon, but the system is Hückel and the reaction is excited-state forbidden.

Hence the preferred reaction stereochemistry at C-1 is disrotatory twisting with respect to C-3 as shown in **18′**.

That we have used a valence bond picture in Chart II and a cyclic orbital array in Chart III is not inconsistent. The biradical formulation **14** can be considered a gradation which occurs early along the reaction coordinate in which overlap between orbitals b and c still is relatively weak. The cyclic array, however, does accommodate the reaction stereochemistry. Also, as we have noted earlier Möbius — $6N$ electron arrays reach a point along the reaction coordinate where S_0 and S_1 surfaces approach one another and internal conversion to ground state of product becomes especially probable.[15,19,20]

In conclusion it is apparent that the di-π-methane stereochemistry is established with certainty at two of the three centers and tentatively the last.

Experimental Section[21]

2,2,4-Trimethyl-3-pentenal. The following is a modification of the procedure of Julia and Baillarg.[8a] A solution of 10 g (0.046 mol) of *cis*- and *trans*-dimethyl-(2,2-dimethyl-3-phenoxycyclo-

(18) (a) H. E. Zimmerman, *J. Amer. Chem. Soc.*, **88**, 1564 (1966). (b) H. E. Zimmerman, *Accounts Chem. Res.*, **4**, 272 (1971). (c) Note that the choice of orbital orientations in Chart III is arbitrary and that inverting some of these will not change the evenness (*i.e.*, Hückel nature) or oddness (*i.e.*, Möbius nature) of the array.

(19) H. E. Zimmerman, *J. Amer. Chem. Soc.*, **88**, 1566 (1966).

(20) H. E. Zimmerman and G. A. Epling, *J. Amer. Chem. Soc.*, **94**, 8749 (1972).

(21) All melting points were determined on a hot-stage calibrated with known compounds.

propyl)methanol[7] in 250 ml of acetone was added to 100 ml of 10% potassium bisulfate and refluxed 3.5 hr. The mixture was poured into water and ether extracted; the ether extracts were washed with 10% sodium hydroxide and then with water. The ether phase was dried and the ether distilled. Distillation of the residue yielded 4.45 g (0.035 mol, 77%) of the aldehyde: bp 45° (17 mm) (lit.[7] 43–44°); nmr ($CDCl_3$) τ 0.55 (s, 1 H), 4.93 (m, 1 H), 8.30 (d, 3 H, J = 1.5 Hz), 8.50 (d, 3 H, J = 1.5 Hz), 8.88 (s, 6 H); ir in agreement with data published by Hasek, *et al.*[8b]

***trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene.** A mixture of 5.0 ml of benzyl chloride and 7.7 ml of triethyl phosphite (freshly distilled from sodium) was heated gradually to 190° over 1.5 hr in a flask equipped with a reflux condenser. The reaction was cooled to 5° and 2.4 g of sodium methoxide in 40 ml of dimethylformamide was added. After the mixture was stirred for 10 min, 2.67 g (20 mmol) of 2,2,4-trimethyl-3-pentenal was added. The reaction was stirred 12 hr and then poured into water and hexane extracted. The extracts were water washed, dried over magnesium sulfate, concentrated, and chromatographed on a 3.7 × 80 cm silicic acid–Celite (3:1) column packed in hexane. This gave 3.68 g (18.4 mmol, 92%) of pure *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene: nmr ($CDCl_3$) τ 2.78 (m, 5 H), 3.68 (s, 2 H), 4.75 (m, 1 H), 8.03 (d, 3 H, J = 1.8 Hz), 8.37 (d, 3 H, J = 1.5 Hz), 8.73 (s, 6 H); ir (neat) 3.29, 3.37, 3.41, 6.10, 6.18, 6.93, 7.30, 7.38, 9.35, 10.35, and 14.50 μ; uv λ_{max} (95% EtOH) 254 nm (ϵ 17,700).

Anal. Calcd for $C_{15}H_{20}$: C, 89.94; H, 10.06. Found: C, 89.84; H, 10.10.

***cis*- and *trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadienes.** *n*-Butyllithium in hexane (20 mmol) was added to a rapidly stirred suspension of benzyltriphenylphosphonium chloride (7.78 g, 20 mmol) in 100 ml of benzene under nitrogen. After 2.5 hr at room temperature, 2.00 g (18 mmol) of 2,2,4-trimethyl-3-pentenal in 20 ml of benzene was added; stirring and reflux were continued 4 hr. The reaction was allowed to cool, the excess ylide was destroyed with 3 ml of water, and solids were filtered and washed with benzene. Concentration of the combined benzene phase resulted in an oil which was chromatographed exactly as above. The hydrocarbon fraction contained 1.412 g (7.05 mmol, 39%) of a mixture of *ca.* 60% *cis*- and 40% *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene. The isomers were separated at 175° on a Prepmaster 776 gas chromatograph fitted with a 2 m × 2.5 cm column of 15% Carbowax 20M on 60–80 Chromosorb W. The cis isomer eluted first followed by a trace of unidentified impurity and then the trans diene. Both cis and trans diene so prepared showed no impurity on a variety of analytical gc columns. Spectral data for *cis*-3,3,5-trimethyl-1-phenyl-1,4-diene were: nmr (CCl_4) τ 2.85 (s, 5 H), 3.67–4.34 (q, 2 H, J = 13 Hz), 4.88 (m, 1 H), 8.46 (d, 3 H, J = 1.8 Hz), 8.56 (d, 3 H, J = 1.8 Hz), and 8.82 (s, 6 H); ir (neat) 3.29, 3.36, 3.40, 6.10, 6.27, 6.92, 7.24, 7.28, 9.34 and 14.36 μ; uv (95% EtOH) λ_{max} 243 nm (ϵ 8750).

Anal. Calcd for $C_{15}H_{20}$: C, 89.94; H, 10.06. Found: C, 90.00; H, 9.92.

***cis*- and *trans*-2,2-Dimethyl-3-phenylcyclopropanecarboxylic Acids.** The method of Sorm and Farkas[12a] was used to obtain the two acids. The trans acid melted at 104–104.5° (lit. 109°) and its nmr and ir spectra were in complete accord with those reported by Roberts, *et al.*[12b] The cis acid melting at 136–136.5° (lit. 134°)[12a] was similarly found to have spectral characteristics identical with those previously reported.[12b]

(*trans*-2,2-Dimethyl-3-phenylcyclopropyl)methanol. A solution of 3.00 g (16 mmol) of *trans*-2,2-dimethyl-3-phenylcyclopropanecarboxylic acid in 65 ml of dry tetrahydrofuran was added to a suspension of 0.91 g (24 mmol) of lithium aluminum hydride in 60 ml of tetrahydrofuran with stirring and ice cooling. Stirring was continued 12 hr followed by refluxing for 30 min. After cooling an excess of a 1:1 mixture of sodium sulfate decahydrate–Celite was added to destroy unreacted lithium aluminum hydride. The mixture was stirred until the gray solid turned white, then the granular precipitate was filtered. Removal of the solvent and vacuum distillation of the residue provided 2.59 g (14.7 mmol, 93%) of the desired alcohol: bp 115° (1.0 mm); nmr (CCl_4) τ 2.90 (s, 5 H), 6.21–6.44 (m, 3 H, –OH and CH_2), 8.33 (d, 1 H, J = 6 Hz, PhCH), 8.58–8.80 (m, 1 H, cyclopropyl H partially obscured by CH_3 singlet), 8.77 (s, 3 H, CH_3), 9.18 (s, 3 H, CH_3); ir (CCl_4) 2.72, 2.95, 3.25, 3.28, 3.34, 6.26, 6.69, 6.91, 7.27, 8.94, 9.38, 9.56, 9.85, 10.48, and 14.36 μ.

Anal. Calcd for $C_{12}H_{16}O$: C, 81.77; H, 9.15. Found: C, 81.69; H, 9.19.

(*cis*-2,2-Dimethyl-3-phenylcyclopropyl)methanol. A procedure identical with that used for the trans alcohol was employed. The reaction of 3.02 g (16 mmol) of *cis*-2,2-dimethyl-3-phenylcyclopropanecarboxylic acid with 1.26 g (33 mmol) of lithium aluminum hydride yielded 2.58 g (14.6 mmol, 92%) of the cis alcohol: bp 105° (1.0 mm); nmr (CCl_4) τ 2.85 (s, 5 H), 6.15–6.78 (m, 2 H, CH_2), 6.80 (s, 1 H, OH), 8.06 (d, 1 H, J = 9.5 Hz, benzylic), 8.67–8.95 (m, mostly obscured by methyls, 1 H, cyclopropyl); 8.78 (s, 3 H, CH_3), and 9.05 (s, 3 H, CH_3); ir (CCl_4) 2.74, 2.99, 3.25, 3.29, 3.34, 6.25, 6.70, 6.92, 7.27, 8.02, 8.80, 8.95, 9.35, 9.55, 9.87, 10.02, 10.45, 13.82, and 14.32 μ,

Anal. Calcd for $C_{12}H_{16}O$: C, 81.77; H, 9.15. Found: C, 81.55; H, 9.06.

***cis*-2,2-Dimethyl-3-phenylcyclopropanecarboxaldehyde.** To a solution of 31.6 g (0.40 mol) of pyridine in 150 ml of glacial acetic acid, 20 g (0.20 mol) of chromium trioxide was carefully added in portions with vigorous stirring while the temperature was kept at 10–15°. The solution was diluted with an additional 250 ml of glacial acetic acid and cooled to 5°; then 3.52 g (20 mmol) of (*cis*-2,2-dimethyl-3-phenylcyclopropyl)methanol in 50 ml of ether was added during 10 min. The mixture was stirred 15 min more, poured into water, and ether extracted. The extract was washed with water and cautiously made basic with solid sodium bicarbonate, then washed once with saturated sodium bicarbonate, dried over magnesium sulfate, and concentrated to give 3.32 g (18.5 mmol, 92%) of *cis*-2,2-dimethyl-3-phenylcyclopropanecarboxaldehyde as a colorless oil: nmr (CCl_4) τ 1.02 (d, 1 H, J = 7 Hz, CHO), 2.82 (s, 5 H), 7.44 (d, J = 8 Hz, 1 H, cyclopropyl CH), 8.22 (d of d, J = 8 Hz and 7 Hz, 1 H, α-CH), 8.73 (s, 6 H, 2 CH_3); ir (neat) 3.29, 3.36, 3.58, 3.61, 5.91, 6.24, 6.69, 6.93, 7.26, 8.75, 8.96, 10.17, 11.77, 12.60, 13.75, and 14.39 μ. The semicarbazone, mp 211–212.5°, was prepared for analysis.

Anal. Calcd for $C_{13}H_{17}ON_3$: C, 67.50; H, 7.41; N, 18.17. Found: C, 67.37; H, 7.44; N, 18.00.

***trans*-2,2-Dimethyl-3-phenylcyclopropanecarboxaldehyde.** The trans aldehyde was prepared exactly as above using 3.52 g (20 mmol) of (*trans*-2,2-dimethyl-3-phenylcyclopropyl)methanol. The yield was 3.29 g (18.4 mmol, 91%) of the desired *trans*-2,2-dimethyl-3-phenylcyclopropanecarboxaldehyde: nmr (CCl_4) τ 0.41 (d, 1 H, J = 4.5 Hz, CHO), 2.84 (s, 5 H), 7.15 (d, 1 H, J = 6 Hz, β-CH), 7.88 (d of d, 1 H, J = 6 Hz, 4.5 Hz, α-CH), 8.60 (s, 3 H, CH_3), 9.02 (s, 3 H, CH_3); ir (neat) 3.29, 3.37, 3.46, 3.65, 5.89, 6.25, 6.70, 6.91, 7.29, 8.13, 8.29, 8.80, 9.00, 10.21, 10.83, 11.65, 12.62, 13.80, and 14.32 μ. The semicarbazone was prepared for analysis, mp 166–167°.

Anal. Calcd for $C_{13}H_{17}ON_3$: C, 67.50; H, 7.41; N, 18.17. Found: C, 67.38; H, 7.40; N, 17.95.

***trans*-3,3-Dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane.** *n*-Butyllithium in hexane (36 mmol) was added in one portion to a rapidly stirred suspension of 17.56 g (39 mmol) of triphenylisopropylphosphonium iodide in 100 ml of dry tetrahydrofuran. The solution became deep red immediately. After 15 min stirring, 5.30 g (37 mmol) of *trans*-2,2-dimethyl-3-phenylcyclopropanecarboxaldehyde was added dropwise in 30 ml of dry tetrahydrofuran. The reaction was stirred overnight and the excess ylide destroyed with water. Precipitated triphenylphosphine oxide was filtered, and the solvent was removed. The crude product was then passed through a 1 m × 2.5 cm column of 3:1 silicic acid–Celite eluting with hexane. The hydrocarbon fraction consisted of 3.18 g (15.9 mmol, 43%) of trans vinylcyclopropane: nmr (CCl_4) τ 2.90 (s, 5 H), 5.00 (d of m, 1 H, =CH–), 8.33 (m, 8 H, allyl CH_3's and two mostly obscured cyclopropyl Hs), 8.82 (s, 3 H, CH_3), 9.15 (s, 3 H, CH_3); ir (CCl_4) 3.23, 3.25, 3.29, 3.35, 3.41, 3.48, 6.24, 6.68, 6.91, 7.25, 7.83, 8.70, 8.95, 9.52, 9.72, and 14.33 μ; uv (95% EtOH) no max, sh 259 nm (ϵ 508).

Anal. Calcd for $C_{15}H_{20}$: C, 89.94; H, 10.06. Found: C, 89.71; H, 10.07.

***cis*-3,3-Dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane.** *n*-Butyllithium (30 mmol) was added to triphenylisopropylphosphonium iodide (14.5 g, 33 mmol) in 100 ml of tetrahydrofuran with rapid stirring; 15 min later 3.07 g (18 mmol) of the cis aldehyde in 30 ml of dry tetrahydrofuran was added dropwise. The reaction was stirred at room temperature for 12 hr, then 3.0 ml of water added to destroy excess ylide. Pentane was added to complete the precipitation of the triphenylphosphine oxide; the solution was concentrated and chromatographed as above. The hydrocarbon fraction yielded 2.87 g (14.3 mmol, 80%) of *cis*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane: nmr (CCl_4) τ 2.90 (s, 5 H), 5.30 (d of m, 1 H, J = 9 Hz, =CH), 8.00 (d, 1 H, J = 9.3 Hz, PhCH), 8.27 (d, 3 H, J = 2 Hz, CH_3), 8.34 (d, 3 H, J = 1 Hz, CH_3), 8.40 (t, 1 H, J = 9.3 Hz, allylic CH), 8.73 (s, 3 H, CH_3), and 9.07 (s, 3 H, CH_3); ir (CCl_4) 3.23, 3.26, 3.29, 3.40, 5.15,

5.35, 5.63, 5.85, 6.24, 6.69, 6.92, 7.25, 7.62, 8.15, 8.48, 8.67, 8.93, 9.30, 9.41, 9.70, 9.78, 13.81, and 14.32 μ; uv (95% EtOH) no max, sh 260 nm (ϵ 1260).

Anal. Calcd for $C_{15}H_{20}$: C, 89.94; H, 10.06. Found: C, 89.79; H, 9.97.

Exploratory Irradiation of *trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene. A solution of 1.00 g (5.0 mmol) of *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene in 200 ml of *tert*-butyl alcohol was purged with nitrogen for 1 hr before and during photolysis. The solution was irradiated 1.5 hr using a Corex-filtered 450-W Hanovia medium-pressure mercury lamp. Distillation of the *tert*-butyl alcohol left 904 mg of oil, the nmr of which showed only traces of starting material remained. Chromatography on a 2.6 × 300 cm silicic acid (Silicar CC-7, 100–200 mesh) column eluting with hexane and monitoring at 254 nm gave the following 40-ml fractions: 1–25, nil; 26–29, 94 mg of 2,2,5,5-tetramethyl-3-phenylbicyclo-[2.1.0]pentane, nmr (CCl_4) τ 2.82 (s, 5 H), 7.10 (d, 1 H, J = 2 Hz, benzylic H), 8.34 (d, 1 H, J = 2 Hz, bridgehead H), 8.43 (d, 1 H, J = 2 Hz, bridgehead H), 8.54 (s, 3 H, CH_3), 8.93 (s, 3 H, CH_3), 9.05 (s, 3 H, CH_3), and 9.32 (s, 3 H, CH_3). The nmr was in agreement with the data of Hammond and Kristinsson.[13] Fractions 29–31, 149 mg of a mixture of the above bicyclic and cis-isomerized hexadiene; 32 and 33, 43 mg of cis hexadiene, identical in all respects with synthetic material; 34–36, 147 mg of *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane contaminated with small amounts of cis and trans starting material; and 37–56, 264 mg of pure *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, identical with the independently synthesized compound.

Preparative Photolysis of *trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene Followed by Preparative Gas Chromatography. Irradiation of 1.009 g (5.0 mmol) of the trans hexadiene was conducted exactly as above. After solvent removal 890 mg of oil remained. Preparative gc (1.75 × 200 cm column of 15% Carbowax 20M on 60–80 Chromosorb W, 150°) resolved four peaks: (a) cis-isomerized hexadiene, 7 mg; (b) *cis*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 11 mg; (c) *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 85 mg; and (d) *syn*-2,2,5,5-tetramethyl-3-phenylbicyclo[2.1.0]pentane, 66 mg. Despite losses due to volatility, this run established the identity of peaks used for analysis.

Preparative Photolysis of *cis*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene Followed by Preparative Gas Chromatography. A solution of 300 mg (1.5 mmol) of the cis hexadiene in 200 ml of *tert*-butyl alcohol was irradiated for 65 min with a Corex-filtered 450-W Hanovia medium-pressure mercury lamp. After removal of solvent, 245 mg of oil remained. This was injected on preparative gc as above and separated into three fractions: (a) unreacted cis hexadiene, 31 mg; (b) a mixture of *cis*- and *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropanes, 15 mg; and (c) *syn*-2,2,5,5-tetramethyl-3-phenylbicyclo[2.1.0]pentane, 6 mg.

Quantum Yield Apparatus and Equipment. Quantum yield photolyses were carried out in the "Black Box" apparatus previously described.[22] Before photolysis, solutions were purged with vanadous-purified nitrogen for 0.5 hr, and during photolysis positive nitrogen pressure was maintained above the solutions.

Filter Solutions. Cell 1 of a triple-compartment filter was filled with 2 *M* nickel sulfate in 5% sulfuric acid, cell 2 with 0.8 *M* cobalt sulfate in 5% sulfuric acid, and cell 3 with 0.0012 *M* bismuth chloride in 10% hydrochloric acid. This filter combination was opaque below 263 nm and above 301 nm; it showed 21% maximum transmittance at 283 nm. For sensitized irradiations 0.1 *M* cupric sulfate replaced the bismuth chloride solution. This combination was opaque below 290 nm and above 345 nm and had a maximum 22% transmission at 322 nm.

Quantum Yield Irradiations. *tert*-Butyl alcohol was distilled from calcium hydride. Solutions of *cis*- or *trans*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene in 750 ml of *tert*-butyl alcohol were irradiated four times; solvent was then concentrated to 50 ml below 45° *in vacuo*. A known amount of biphenyl was added as standard and the mixtures were analyzed by vpc at 145° on a 4 m × 4 mm column packed with 15% Carbowax 20M on 80–100 Chromosorb W.

Run 1. *trans*-1-Phenyl-3,3,5-trimethyl-1,4-hexadiene (175 mg, 0.875 mmol) in 750 ml of *tert*-butyl alcohol; 1.05 mEinsteins; 14.7 mg of biphenyl; *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 19.1 mg, 0.0956 mmol; Φ = 0.091; 3-phenyl-2,2,5,5-tetramethylbicyclo[2.1.0]pentane, 14.9 mg, 0.0744 mmol; Φ = 0.071; *cis*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 7.2 mg, 0.0362 mmol; Φ = 0.034; recovered *trans*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 116 mg, 0.581 mmol.

Run 2. *trans*-1-Phenyl-3,3,5-trimethyl-1,4-hexadiene (200 mg, 1.00 mmol) in 750 ml of *tert*-butyl alcohol; 1.48 mEinsteins, 14.7 mg of biphenyl; *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 27.8 mg, 0.139 mmol; Φ = 0.094; 3-phenyl-2,2,5,5-tetramethylbicyclo[2.1.0]pentane, 22.6 mg, 0.113 mmol; Φ = 0.076; *cis*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 10.7 mg, 0.0535 mmol; Φ = 0.036; recovered *trans*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 133 mg, 0.663 mmol.

Run 3. *cis*-1-Phenyl-3,3,5-trimethyl-1,4-hexadiene (309 mg, 1.54 mmol) in 750 ml of *tert*-butyl alcohol; 0.491 mEinsteins, 20.2 mg of biphenyl; *cis*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 4.5 mg, 0.0266 mmol, Φ = 0.046; *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 1.3 mg, 0.0066 mmol, Φ = 0.013; 3-phenyl-2,2,5,5-tetramethylbicyclo[2.1.0]pentane, 0.3 mg, 0.0014 mmol, Φ = 0.003; unidentified material (assumed isomeric), 0.3 mg, 0.0014 mmol, Φ = 0.003; *trans*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 3.5 mg, 0.0176 mmol, Φ = 0.034; recovered *cis*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 302 mg, 1.51 mmol.

Run 4. *cis*-1-Phenyl-3,3,5-trimethyl-1,4-hexadiene (357 mg, 1.78 mmol) in 750 ml of *tert*-butyl alcohol; 0.381 mEinsteins; 42.8 mg of biphenyl; *cis*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 4.3 mg, 0.0215 mmol, Φ = 0.056; *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 0.8 mg, 0.0041 mmol, Φ = 0.011; 3-phenyl-2,2,5,5-tetramethylbicyclo-[2.1.0]pentane, 0.4 mg, 0.0020 mmol, Φ = 0.005; unidentified material, 0.3 mg, 0.0013 mmol, Φ = 0.003; *trans*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 3.5 mg, 0.0172 mmol, Φ = 0.045; recovered *cis*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 356 mg, 1.78 mmol.

Run 5. *cis*-1-Phenyl-3,3,5-trimethyl-1,4-hexadiene (306 mg, 1.53 mmol) in 750 ml of *tert*-butyl alcohol; 0.494 mEinsteins; 42.8 mg of biphenyl; *cis*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 4.9 mg, 0.0245 mmol, Φ = 0.050; *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 1.3 mg, 0.00659 mmol, Φ = 0.013; 3-phenyl-2,2,5,5-tetramethylbicyclo-[2.1.0]pentane, 0.6 mg, 0.00295 mmol, Φ= 0.006; unidentified material, 0.4 mg, 0.00224 mmol, Φ = 0.004; *trans*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 4.1 mg, 0.0206 mmol, Φ = 0.042; recovered *cis*-1-phenyl-3,3,5-trimethyl-1,4-hexadiene, 300 mg, 1.50 mmol.

Run 6. *trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene (499 mg, 2.49 mmol) in 750 ml of *tert*-butyl alcohol; 0.324 mEinsteins; 3.51 mg of biphenyl; *cis*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 2.62 mg, 1.32×10^{-2} mmol, Φ = 0.041; *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 6.82 mg, 3.42×10^{-2} mmol, Φ = 0.106; 2,2,5,5-tetramethyl-3-phenylbicyclo[2.1.0]pentane, 5.54 mg, 2.76×10^{-2} mmol, Φ = 0.086; *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 519 mg, 2.59 mmol.

Run 7. *trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene (517 mg, 2.59 mmol) in 750 ml of *tert*-butyl alcohol; 1.016 mEinsteins; 17.9 mg of biphenyl; *cis*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 7.28 mg, 3.64×10^{-2} mmol, Φ = 0.036; *trans*-3,3-dimethyl-2-(2′,2′-dimethylvinyl)-1-phenylcyclopropane, 20.1 mg, 1.01×10^{-1} mmol; Φ = 0.099; 2,2,5,5-tetramethyl-3-phenylbicyclo[2.1.0]-pentane, 16.0 mg, 8.00×10^{-2} mmol, Φ = 0.079; *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 457 mg, 2.28 mmol.

Sensitized Irradiations. Run A. *trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene (401 mg, 2.00 mmol) and 4.000 g of benzophenone in 750 ml of *tert*-butyl alcohol; 6.99 mEinsteins; 29.4 mg of biphenyl; *cis*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 146 mg, 7.30×10^{-1} mmol, Φ = 0.104; *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 237 mg, 1.19 mmol.

Run B. *trans*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene (248 mg, 1.24 mmol) and 4.003 g of benzophenone in 750 ml of *tert*-butyl alcohol; 3.48 mEinsteins; 25.8 mg of biphenyl; *cis*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 81.0 mg, 4.05×10^{-1} mmol, Φ = 0.115; *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 151 mg, 7.50×10^{-1} mmol.

Run C. *cis*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene (286.5 mg, 1.43 mmol) and 2.000 g of benzophenone in 750 ml of *tert*-butyl alcohol; 1.99 mEinsteins; 43.6 mg of biphenyl; *cis*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 231 mg, 1.16 mmol; *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 37 mg, 1.85×10^{-1} mmol, Φ = 0.093.

Run D. *cis*-3,3,5-Trimethyl-1-phenyl-1,4-hexadiene (433 mg,

(22) H. E. Zimmerman, *Mol. Photochem.*, 3, 281 (1971).

2.16 mmol) and 4.006 g of benzophenone in 750 ml of *tert*-butyl alcohol; 1.095 mEinsteins; 9.31 mg of biphenyl; *cis*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 312 mg, 1.56 mmol; *trans*-3,3,5-trimethyl-1-phenyl-1,4-hexadiene, 20 mg, 1.00×10^{-1} mmol, $\Phi = 0.087$.

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Conformational Studies of 1,3-Thiazolidines

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Abstract: The nmr spectra of 1,3-thiazolidine, 2-*tert*-butyl-1,3-thiazolidine, *N,S*-diacetylcysteamine, *N,N,S*-triacetylcysteamine, cysteamine hydrochloride, sodium 2-aminoethylmercaptide, and bisaminoethyl disulfide have been obtained and completely analyzed. On the basis of the coupling constants the thiazolidines are considered to exist in conformations close to envelopes with either C-4 or C-5 as the flap atom and with the 2 substituent anti to the flap (**2** or **3a**).

Conformational analysis of five-membered rings by nmr methods is often made difficult by the profusion of nearly equienergy conformers which must be considered and by the inadequacy of the Karplus equation for determination of reliable rotational angles. In spite of these difficulties, considerable progress has been made with five-membered rings having an ethylene group isolated by heteroatoms in the 1 and 3 positions. These include 1,3-dioxolanes,[2-8] 1,3-dithiolanes,[9] and 1,3-oxathiolanes.[9-11] Research in these laboratories directed toward analyzing preferred conformations of coenzyme A necessitated study of the nmr spectra of acyclic cysteamine derivatives possessing an ethylene bridge separating sulfur and nitrogen atoms. A study of 1,3-thiazolidine and its 2-*tert*-butyl derivative was also needed as a means to define model coupling constants for gauche- and trans-related vicinal protons in the SCH_2CH_2N unit. The results of these investigations of model systems permit us to discuss the preferred conformation of the thiazolidines studied and to compare the rotational angles of thiazolidines to those of previously studied heterocycles.

Results

N,S-Diacetylcysteamine (I) and *N,N,S*-triacetylcysteamine (II) together with *N*-acetylcysteamine (III) were all obtained by acetylation of cysteamine using an excess of acetic anhydride. 2-*tert*-Butyl-1,3-thiazolidine (IV) was prepared from cysteamine hydrochloride and pivaldehyde according to the method of Tondeur, Sion, and Deray.[12]

The magnetic environments of enantiotopic protons of enantiomeric gauche rotamers of cysteamine derivatives are averaged by rotation about the C–C bond. Similarly, the enantiotopic protons of enantiomeric ring conformations of thiazolidine undergo averaging by the process of rapid pseudorotation. The diastereotopic protons of enantiomeric ring conformations of 2-substituted thiazolidines, of necessity, remain diastereotopic under pseudorotation. Thus the 60-MHz spectra of thiazolidine (Figure 1), cysteamine hydrochloride (Figure 2), sodium 2-aminoethylmercaptide, bis-2-aminoethyl sulfide, *N,S*-diacetylcysteamine (Figure 3), and *N,N,S*-triacetylcysteamine (Figure 4) all consisted of 14 line symmetrical AA′BB′ patterns in which the multiplets of one-half of the spectrum were broadened by additional coupling to nitrogen. Spectral parameters (Table I) were obtained in each of these cases by computer assisted nmr analysis using LAOCN3[13] ignoring the nitrogen coupling; however, the necessity to assign weak transitions buried under large peaks made the solutions difficult for many of the spectra. Calculated spectra were plotted by a CALCOMP 27 plotter using a program (LORE) which sums Lorentzian curves substituted for each spectral line. The quality of the fit was judged in each case by comparison of line positions and intensities of plotted spectra with the experimental spectrum. The validity of the solutions for cysteamine hydrochloride and acetylcysteamines was assessed by calculation of the 220-MHz spectrum using the parameters obtained at 60 MHz and comparison of the plots with the observed spectrum. In each case except *N,N,S*-triacetylcysteamine, the 220-MHz spectrum proved to be a six line "deceptively simple" [14] pattern. The complex spectrum

(1) Taken from the Ph.D. Thesis of T. J. B. submitted in partial fulfillment of the requirements for the Ph.D. degree in chemistry of the Polytechnic Institute of Brooklyn.
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