"neutralized" by the system. The general biological relevance of slowing down is presently an open question.

Acknowledgment. We thank H. Schraut for expert technical assistance and M. Heinrichs for stimulating discussions. We also thank the Fonds der Chemischen Industrie for partial support of this work.

Registry No. Trypsinogen, 9002-08-8; trypsin, 9002-07-7.

Stereospecific Photodecarbonylation of *cis*- and *trans*-2,7-Dimethyl-3,5-cycloheptadienone: Observation of an Apparent Symmetry-Forbidden Concerted Cheletropic Fragmentation[1]

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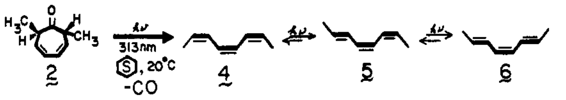
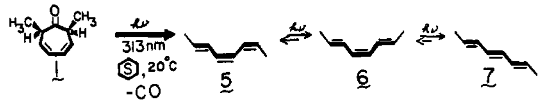
We have previously reported that photodecarbonylation of 3,5-cycloheptadienones occurs from a short-lived singlet electronic excited state of mixed electronic configuration[2,3] and speculated that the mechanism of this reaction involves simultaneous cleavage of both bonds to the carbonyl carbon, i.e., a concerted cheletropic fragmentation.[5,6] However, a stepwise mechanism invoking acyl–alkyl diradicals could not be excluded from consideration. We now report that the analogous reactions of *cis*- and *trans*-2,7-dimethyl-3,5-cycloheptadienone (**1** and **2**) are stereospecific and occur with conrotation at the methyl-bearing carbons to give initially (*Z,Z,E*)- and (*Z,Z,Z*)-2,4,6-octatriene, respectively, which then undergo further isomerization (see eq 1 and 2).



(1)



(2)

The synthesis of **1** and **2** from tropone will be described in detail elsewhere.[18] These compounds, purified by HPLC, readily isomerize thermally to 2,7-dimethyl-2,4-cycloheptadienone (**3**) under a variety of conditions but are stable on storage at low temperatures. The assignment of stereochemistry to **1** and **2** is based on NMR spectra of their Diels–Alder adducts with 4-phenyl-1,2,4-triazolin-3,5-dione and an X-ray structure of the adduct of *cis*-dienone **1**.[7]

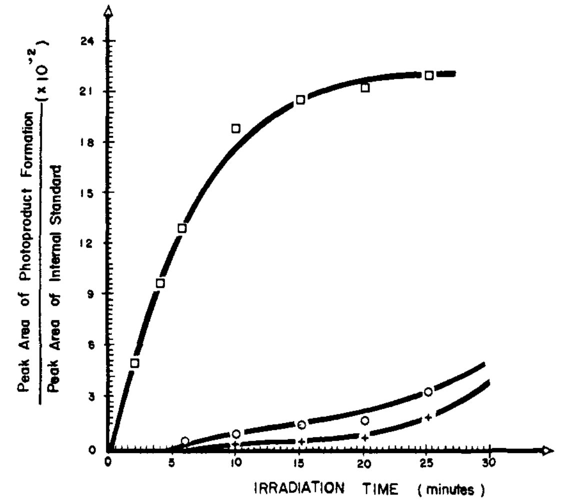


Figure 1. Irradiation of **2** (0.0610 M) in cyclohexane at 313 nm (20 °C). Photoproducts (*Z,Z,Z*)-, (*E,Z,Z*)-, and (*E,Z,E*)-2,4,6-octatriene (**4–6**, respectively) are represented by □, ○, and +, respectively.

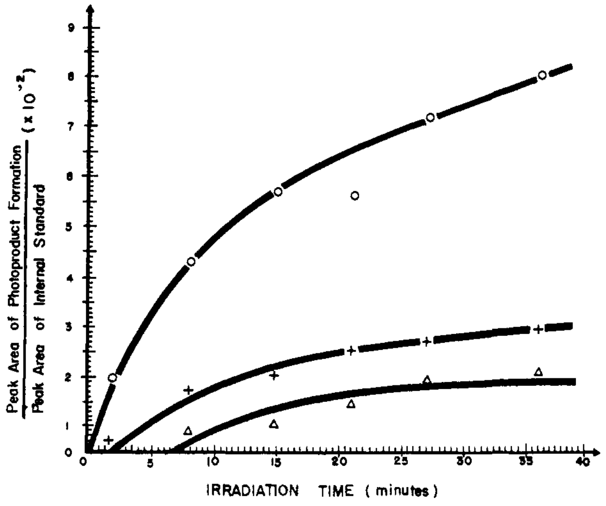


Figure 2. Irradiation of **1** (0.0690 M) in cyclohexane at 313 nm (20 °C). Photoproducts (*E,Z,Z*)-, (*E,Z,E*)-, and (*E,E,E*)-2,4,6-octatriene (**5–7**, respectively) are represented by ○, +, and △, respectively.

The three trienes **4–6** were independently synthesized according to the method of Marvell,[8] separated and purified by preparative GLC, and characterized by UV[8] and NMR spectroscopy. The all-trans *E,E,E* isomer **7**, mp 50–51 °C, was prepared by irradiation of the other trienes. The products of irradiation of **1** and **2** in cyclohexane at 313 nm were analyzed by GLC with an internal standard (*n*-tridecane) at various intervals of time, with the results as shown in Figures 1 and 2. No interconversion of dienones **1** and **2** was detected during the irradiations, thus excluding reversible formation of an acyl–akyl diradical that can undergo bond rotation prior to ring closure.[9]

These 3,5-cycloheptadienones are believed to possess a molecular structure with C_2 symmetry containing a twisted diene moiety.[2-4] In such a structure, the methyl groups of the *cis*-dienone **1** would occupy pseudoquatorial and pseudoaxial positions, while the methyls in the *trans*-dienone **2** are both either pseudoaxial or pseudoequatorial. Molecular mechanics calculations are in progress to determine which of the conformations of **2** is more

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[1] Photochemistry of Ketones in Solution. 70. Part 69: Brisimitzakis, A. C.; Schuster, D. I. *Tetrahedron Lett.* **1982**, *44*, 4535.

[2] Schuster, D. I.; Sckolnick, B. R.; Lee, F.-T. H. *J. Am. Chem. Soc.* **1968**, *90*, 1300. Schuster, D. I.; Kim, C. W. *Ibid.* **1974**, *96*, 7437.

[3] INDO calculations indicate that the S_1 state of 3,5-cycloheptadienones with overall C_2 symmetry is highly mixed configurationally, with about 80% contribution from an n,π^* configuration. Extinction coefficients for absorption above 290 nm are greatly enhanced over those for corresponding α,β-enones or saturated ketones, as is typical for twisted β,γ-enones.[4] For a full discussion of the photochemistry and spectroscopy of these systems, see: Schuster, D. I.; Eriksen, J. *J. Org. Chem.* **1979**, *44*, 4254.

[4] For a review on the photochemistry and spectroscopy of β,γ-enones, see: Schuster, D. I. "Rearrangements in Ground and Excited States"; de Mayo, P., Ed.; Academic Press: New York, 1980; Vol. 3, Essay 17. See also: Houk, K. N. *Chem. Rev.* **1976**, *76*, 1.

[5] Woodward, R. B.; Hoffmann, R. "The Conservation of Orbital Symmetry"; Verlag Chemie/Academic Press: New York, pp 152 ff.

[6] For a review of cheletropic reactions, see; Mock, W. L. In "Pericyclic Reactions"; Marchand, A. P., Lehr, R. E., Eds.; Academic Press: New York, 1977; Vol. II, pp 141–179.

[7] Studies carried out in collaboration with Professor J. M. van der Veen, Stevens Institute of Technology, to be published elsewhere.

[8] Schatz, B. S. Ph.D. Dissertation, Oregon State University, 1967. Marvell, E. N.; Caple, G.; Schatz, B. *Tetrahedron Lett.* **1965**, 385.

[9] The role of acyl–alkyl diradicals in the photochemistry of cyclohexanones has been discussed in detail by Rickborn and co-workers: Badcock, C. C.; Perona, M. J.; Pritchard, G. O.; Rickborn, B. *J. Am. Chem. Soc.* **1969**, *91*, 543. Alumbaugh, R. L.; Pritchard, G. O.; Rickborn, B. *J. Phys. Chem.* **1965**, *69*, 3225.

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stable; Dreiding models suggest it may well be the pseudoaxial conformation.

A linear thermal cheletropic fragmentation of 1-X-3,5-cycloheptadiene is predicted to occur by an axisymmetric[10] conrotatory motion around the end carbons of the residual triene moiety.[5] However, a nonlinear cheletropic fragmentation with disrotation is also allowed thermally.[5] An equivalent analysis of the reverse addition of X to 1,3,5-hexatriene shows it should involve a linear approach of X with antarafacial bonding to the triene or a nonlinear superfacial interaction.[11] Mock[12] has observed that thermal extrusion of SO_2 from stereoisomeric sulfones structurally analogous to **1** and **2** indeed occurs by the predicted axisymmetric conrotatory path. Thus, one would predict that if the photoinduced extrusion of CO from **1** and **2** should occur by the stereochemical mode opposite to that of the analogous ground-state system studied by Mock,[12] on the assumption that orbital symmetry is the controlling factor in this system,[13] expulsion of CO along the axis of symmetry of these molecules on photoexcitation is predicted to be accompanied by disrotation in formation of the trienes, contrary to our experimental observation. Such a disrotatory extrusion of CO has been observed[3,14,15,16] on photoexcitation of bridged bicyclic analogues of these dienones, which do not have any other viable alternative.

The possibility that these stereospecific decarbonylations are not concerted seems remote, since the *cis*- and *trans*-dienones are not interconverted and since **2** shows a clear preference for forming the *Z,Z,Z*-triene **4** rather than any of the other more stable triene isomers. For a nonlinear extrusion of CO, i.e., where CO does not depart along the axis of symmetry of the starting dienones, the selection rules[5] would be reversed, consistent with the experimental observations, but there seems to be no compelling reason why such a course should be followed.[19] The precise direction of departure of CO and analogous cheleofuges is not subject to experimental verification by an ordinary stereochemical experiment but perhaps could be analyzed theoretically. Other rationalizations revolve around considerations of the stereoelectronic control exercised by the n,π^* configuration of the excited state of these cycloheptadienones,[3,13] and the rather remote possibility that the reaction is occurring on the ground-state potential surface following internal conversion from S_1. Finally, examination of Dreiding models indicates that in these twisted dienones the pseudoequatorial groups at C_2 and C_7 (H or CH_3) are nearly coplanar with the substituents (H in this instance) at C_3 and C_6, so that the conrotatory pathway (which amounts to little more than rehybridization) represents the path of least motion and would afford trienes in which these groups are on the same side (i.e., cis) of the terminal C═C bonds; disrotation would cause much greater structural distortions. On this basis, one can rationalize the preferred formation of **4** from **2** if **2** is reacting primarily through the conformation in which the methyls occupy pseudoaxial positions.

In summary, we have observed that the photochemical extrusion of CO from cycloheptadienones **1** and **2** occurs stereospecifically by the same axisymmetric conrotatory mode seen in thermal extrusion of SO_2 from the analogous sulfones.[12] Since few reactions of this type have been studied,[6,17] it remains to be seen what factors control the course of cheletropic fragmentations, particularly those induced by light.

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Registry No. 1, 85236-00-6; **2**, 85236-01-7.

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(13) A referee points out that it may well be naive to expect that a photochemical reaction proceeding via an n,π^* state with excitation localized on the carbonyl group should of necessity follow a course opposite to that dominated by the diene moiety in an analogous ground-state reaction. In the case of an n,π^* excited state, where according to the well-known description of Zimmerman[14] there is a lone electron in a p_y orbital parallel to the bonds between the carbonyl and the adjacent carbons and another electron in the antibonding π^* orbital, the stereoelectronic features of this state might well dominate the course of reaction. Some sort of twisting motion is clearly needed to generate ground-state CO, and simple considerations would lead to the expectation that a 90° twist around the C–O bond would be accompanied by rotations of the bonding orbitals of the C–O bonds in a conrotatory fashion, so as to maintain maximum bonding along the energy surface leading to the products. However, it should be kept in mind that the reactive excited state of these 3,5-cycloheptadienones is not a pure n,π^* state, so the relevance of these arguments is by no means clear at this time.

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(17) The same stereospecificity was observed in a photochemical and thermal retrograde homo-Diels–Alder reaction involving extrusion of nitrogen. Other electronic factors may be operating in that system that may not be appropriate to the present case. See: Berson, J. A.; Olin, S. S. *J. Am. Chem. Soc.* **1970**, *92*, 1086.

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(19) However, see Schippers et al. (Schippers, P. H.; van der Ploeg, J. P. M.; Dekkers, H. P. J. M. *J. Am. Chem. Soc.* **1983**, *105*, 84) for evidence of distortion of $^1n,\pi^*$ states of β,γ-enones.

Cooperative Dioxygen Binding by Cobalt(II) Gable Porphyrin in Homogeneous Solution

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The nature of cooperativity in protein action has been gradually elucidated in recent years. Cooperative dioxygen binding by hemoglobin, for example, is now reasonably understood as follows. The O_2 affinity of the T state is remarkably reduced due to intersubunit interaction, but the T state is converted to a high affinity form, R state, on O_2 binding. This conformation change induces the T → R conformation change in the remaining vacant binding sites of the tetrameric protein. Similarly, successive O_2 binding further drives the conformation change. Thus O_2 affinity finally approaches the "normal" value of myoglobin.[1] Among the events involved, the most important yet perhaps most difficult to understand seems to be the structural change of the "coupling site" that transfers the information for O_2 binding from one binding site to the other. In order to gain more insights into the mechanism of information transmission by the structural change of the coupling site, several attempts have been made to *mimic* the cooperative dioxygen binding by using solid metalloporphyrin[2,3] or metalloporphyrin attached to a polymer.[4] Although these systems showed large Hill coefficients, this is primarily due to multisite interaction.[5] Mechanistic details on the molecular basis have not yet been clarified.

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