chloride–ether to give *dl*-cycloheximide, m.p. 137–139° (0.2 g.). A specimen recrystallized from the same solvent pair afforded the pure material, m.p. 139–140.5°. It showed infrared absorption peaks (Nujol mull) at 2.86, 3.12, 3.24, 5.81, 5.92, 7.10, 7.83, 7.90, 8.63, 8.82, 9.02, 9.67, and 11.80 μ. In chloroform solution (1%) it showed bands at 2.81, 2.96, 5.85, 7.23, 8.70, 8.99, 9.68, 10.85, and 11.08 μ and its n.m.r. spectrum in deuteriochloroform showed two methyl doublets at 58.2 (J = 6.1 c.p.s.) and 73.6 c.p.s. (J = 6.7 c.p.s.). The latter two solution spectra were indistinguishable from the corresponding spectra of *l*-cycloheximide, recorded under the same conditions. *Anal.* Calcd. for $C_{15}H_{23}NO_4$: C, 64.0; H, 8.2; N, 5.0. Found: C, 64.3; H, 8.1; N, 5.0.

B. **By Oxidation of *dl*-Dihydrocycloheximide (XVIII).** An aqueous solution of 1 N chromium trioxide (9.3 ml.) containing sulfuric acid (60 ml./l. of solution) was added dropwise with stirring to the diol XVIII (1.1 g.) in acetone distilled from potassium permanganate (30 ml.) at 0–2° during 15 min. The mixture was then allowed to stand in the refrigerator for 48 hr. at 0°. The product, isolated in the usual, was triturated with ether and the solid (0.4 g.) removed by filtration. This was recrystallized from a dilute solution in ether and afforded large hard crystals, m.p. 110–120° (150 mg.). Three further crystallizations from aqueous acetone then afforded essentially pure *dl*-cycloheximide (45 mg.), m.p. 138–139°, which did not depress the melting point of a specimen prepared according to method A above, m.m.p. 138–140°. The infrared spectra of the two specimens were also identical.

***l*-Cycloheximide** (I). *d*-Cycloheximide chloroacetate (0.5 g.) was stirred overnight at room temperature with a solution of methanol (10 ml.) and water (4 ml.) containing potassium bicarbonate (0.84 g.). The methanol then was removed under reduced pressure and the organic product was isolated in the usual way. This material (0.39 g.) could not be crystallized and therefore was dissolved in methylene chloride and chromatographed on a silica gel (10 g.) column. Elution of the column with methylene chloride containing 35% ethyl acetate initially gave starting material (51 mg.) but later fractions (14 25-ml. portions) yielded crude *l*-cycloheximide (190 mg.). Recrystallization of this material from methylene chloride–ether then afforded the pure material, m.p. 115–116°, $[\alpha]^{24}\text{D}$ −33° (c 1.0, $CHCl_3$), whose infrared spectrum was identical with an authentic sample, m.p. 114–115°, $[\alpha]^{24}\text{D}$ −33.8° (c 1.0, $CHCl_3$). No depression in melting point was observed when these two samples were mixed, m.m.p. 114–115°. *Anal.* Calcd. for $C_{15}H_{23}NO_4$: C, 64.0; H, 8.2; N, 5.0. Found: C, 63.8; H, 8.2; N, 5.1.

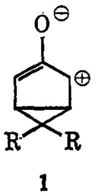
Acknowledgment. The authors wish to thank Drs. W. B. Trapp and H. E. Hennis of the Midland Division of the Dow Chemical Co. who carried out the large-scale preparations of *cis*-2,4-dimethylcyclohexanone and Mr. D. H. Croope for the preparation of a large amount of 3-carboxymethylglutarimide. The technical assistance of Mr. C. A. Brown is gratefully acknowledged. Microanalyses were carried out by Dr. C. K. Fitz, Needham, Mass.

Communications to the Editor

The Relation of Cyclohexenone to Cyclohexadienone Rearrangements. Mechanistic Organic Photochemistry. XIV[1]

Sir:

The photochemical rearrangements of 4,4-disubstituted cyclohexadienones are well known, and mechanisms involving the mesoionic zwitterions **1** and **2** have been proposed in our earlier publications.[2,3]



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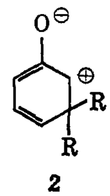
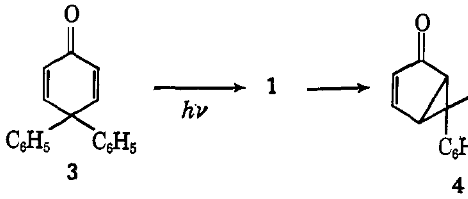


2

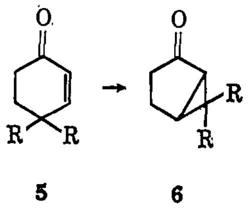
One such rearrangement, conveniently termed type A, is typified by the 4,4-diphenylcyclohexadienone (**3**) to 6,6-diphenylbicyclo[3.1.0]hex-3-en-2-one (**4**) conversion.[3] We suggested this to proceed *via* zwitterion **1** (R = C_6H_5).



(1)

Type A dienone rearrangement

Although our proposal of the intermediacy of **1** and **2** in dienone photochemistry seems accepted,[4,5] doubt is cast by the occurrence of type A skeletal changes on irradiation of 4,4-dialkylcyclohexenones.[6] In the monoenones there is no second double bond to par-



(2)

Type A enone rearrangement

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[1] For Paper XIII of the series note: H. E. Zimmerman, *Pure Appl. Chem.*, **9**, 493 (1964).

[2] H. E. Zimmerman, 17th National Organic Chemistry Symposium, June 1961, Abstracts, p 31.

[3] (a) H. E. Zimmerman and D. I. Schuster, *J. Am. Chem. Soc.*, **83**, 4486 (1961); (b) *ibid.*, **84**, 4527 (1962).

[4] O. L. Chapman, *Advan. Photochem.*, **1**, 323 (1963).

[5] P. J. Kropp, *J. Am. Chem. Soc.*, **85**, 3779 (1963).

[6] (a) W. W. Kwie, B. A. Shoulders, and P. D. Gardner, *ibid.*, **84**, 2268 (1962); (b) O. L. Chapman, T. A. Rettig, A. I. Dutton, and P. Fitton, *Tetrahedron Letters*, 2049 (1963); (c) B. Nann, D. Gravel, R. Schorta, H. Wehrli, K. Schaffner, and O. Jeger, *Helv. Chim. Acta*, **46**, 2473 (1963).

Table I. Quantum Yields of Rearrangement

Enone[a]	Sensitizer or quencher	Solvent	Quantum yield, ϕ
Phenanthrone	None	t-BuOH	0.0084
Phenanthrone	Naphthalene (0.0778 *M*)	t-BuOH	0.0012
Phenanthrone	Di-t-butylnitroxyl (0.043 *M*)	t-BuOH	0.0025
Phenanthrone	Acetophenone (0.200 *M*)	t-BuOH	0.0086
Octalone	None	t-BuOH	0.0038
Octalone	None	MeOH	0.0040
Octalone	None	C_6H_6	0.0061[b]
Octalone	Acetophenone (0.267 *M*)	t-BuOH	0.0055
Octalone	Acetophenone (0.187 *M*)	C_6H_6	0.0134[b]

[a] All octalone runs with 305–365 mμ filter, phenanthrone runs with 320–370 mμ filter; inappreciable absorption by naphthalene, 10% by $(t\text{-Bu})_2NO$ taken into account, essentially complete absorption by acetophenone [b] Quantum yield of photoketone; by-products formed not included.

ticipate, an intermediate such as **1** cannot be involved, and our dienone mechanism is unavailable to the molecule.

In the special case of the 4,4-diphenyl system, the second double bond was shown necessary for the type A reaction and the suggestion based on imperfect logic[7] was made[8] that the order of reaction efficiencies is type A dienone > 4-aryl migration to C-3 > 4,4-dialkyl type A rearrangement.

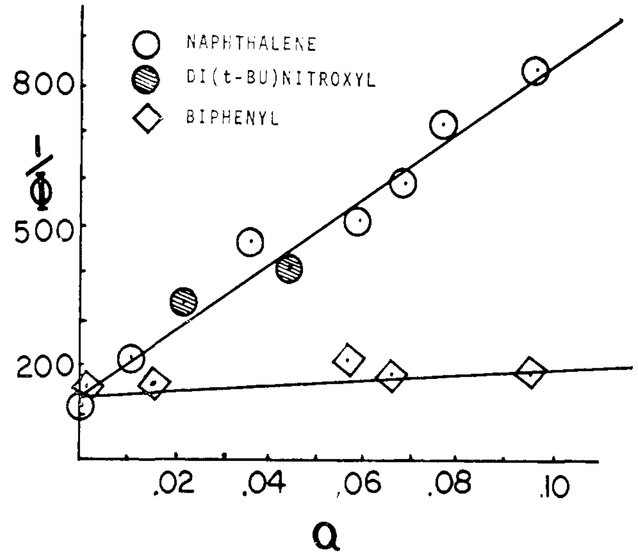
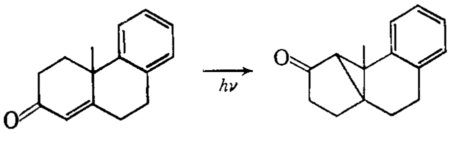


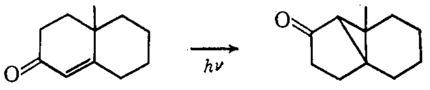
Figure 1. Reciprocal of quantum yield *vs.* quencher concentration.

We now report (i) that the enone triplet does the rearranging as known[9] for the dienone; (ii) that the enone triplet rearranges at most $^1/_{10,000}$ as rapidly as the dienone triplet and 200-fold less efficiently; (iii) that the triplet rearranging either is a hydrogen abstractor itself or is in exceedingly rapid equilibrium with such a triplet; (iv) that the hydrogen abstraction is 100-fold less rapid than that of the benzophenone triplet. The evidence demonstrates that the monoenone rearrangement does have a very inefficient pathway and has little in common with the dienone reaction.

Photolysis[10a] of 4a-methyl-4,4a,9,10-tetrahydro-2(3H)phenanthrone (**7**) afforded photoisomer **8**. Analogously, $\Delta^{1,9}$-10-methyl-2-octalone (**9**) gave photoproduct **10**. The structure of **8** was demonstrated by degradation[11a] to 1-methyl-1-carboxymethyl-2-tetralone, while the structure **10** was established by synthesis.[11b] These are seen to be type A enone rearrangements as in eq 2. Representative quantum efficiencies are given in Table I and are very low (0.001–0.008) compared with the 0.86 quantum yield[12] found for the formally similar dienone reaction in eq 1. The low efficiency was not due to poor intersystem crossing since the acetophenone-sensitized reaction, at least in the phenanthrone case, was close to that of the unsensitized one.



7 **8** (3)



9 **10** (4)

Confirmation of the low reactivity was found in a plot (*cf.* Figure 1) of $1/\phi$ *vs.* quencher concentrations for the phenanthrone reaction. Since the measured phenanthrone triplet energy (71 kcal/mole) is considerably greater than that of naphthalene (61 kcal/mole), one would expect diffusion controlled quenching. This is evidenced by the finding that the paramagnetic di-t-butylnitroxyl[13] runs lie on the same plot. Two such widely different quenchers would be equally effective only if a common factor as diffusion control were operative. The slope is k_q/k_r, where the rate of diffusion estimated as 2×10^9 l. mole^{-1} sec^{-1} is used for k_q, allowing us to obtain the rate of triplet rearrangement k_r as 3×10^5 sec^{-1}, a rate at least 10^4 slower than the dienone case.[12]

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(7) Our reasoning used comparison of intramolecular preference to predict relative intermolecular efficiencies.

(8) H. E. Zimmerman and J. W. Wilson, *J. Am. Chem. Soc.*, **86**, 4036 (1964).

(9) H. E. Zimmerman and J. S. Swenton, *ibid.*, **86**, 1436 (1964).

(10) (a) All photolyses were made using a 1000-w high-pressure Hg lamp with parabolic reflector, solution filters, thermostated cell, and ferrioxalate or uranyl oxalate actinometer. (b) Satisfactory analyses were obtained on all new compounds.

(11) (a) Essentially the same degradation has been independently utilized by O. L. Chapman (private communication). (b) The critical step involves the copper-catalyzed cyclization of 2-methyl-1-cyclohexene-1-propionyldiazomethane. Professor C. D. Gutsche has informed us of his independent finding of the same reaction.

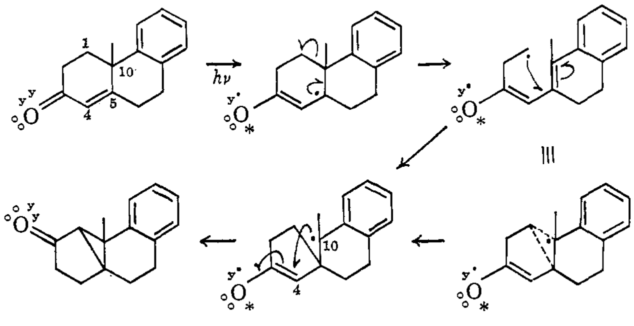
(12) Unpublished findings of H. E. Zimmerman and J. S. Swenton.

(13) A. K. Hoffman, A. M. Feldman, E. Gelblum, and W. Hodgson, *J. Am. Chem. Soc.*, **86**, 639 (1964).

In runs in isopropyl alcohol the pinacol of phenanthrone **7** was formed *ca.* one-fifth as fast as **8**. Photoketone and pinacol formation were quenched equally by naphthalene, signifying that the same triplet is responsible for both reactions, or alternatively that two exceedingly rapidly equilibrating states are involved, one in each reaction. The rate of hydrogen abstraction calculated from this data is $k_h^{bi} = 3 \times 10^3$ l. mole^{-1} sec^{-1}, which is slow compared to the acetophenone abstraction rate in the same solvent,[14] suggesting either that a π–π* triplet is the dominant species, that hydrogen abstraction is reversible, or that n–π abstraction rates vary.

The rearrangement is only slightly solvent dependent and not suggestive of the reaction of a polar species. This accords with our recent finding that the β carbon of the enone moiety is not electron deficient.[15] The very low rate and efficiency of rearrangement contrast with the dienone case and a different, less efficient mechanism is required. Such a mechanism is shown in Scheme I. The 4–10 bond formation of the last step may be concerted with the 10–5 migration of the carbon-1 methylene, and MO calculations indicate this to be favorable. The inefficiency is then seen to derive either solely from the requirement for σ bond (1–10) fission and lack of a second double bond for interaction in the excited state or from this factor coupled with the intervention of a low energy π–π* triplet. Both factors differ in the dienone case.

Scheme I



* = y, if n-π*, or ·, if π-π*

Acknowledgment. Support of this research by the National Science Foundation and by National Institutes of Health Grant GM07487 is gratefully acknowledged.

(14) S. G. Cohen, D. A. Laufer, and W. Sherman, *J. Am. Chem. Soc.*, **86**, 3060 (1964).

(15) H. E. Zimmerman, R. C. Hahn, H. Morrison, and M. C. Wani, *ibid.*, **87**, 1138 (1965).

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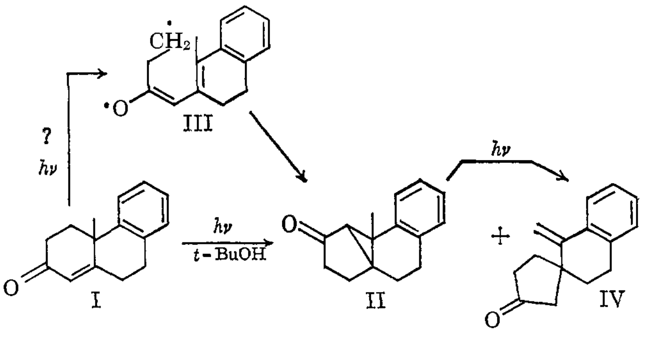
Received October 4, 1965

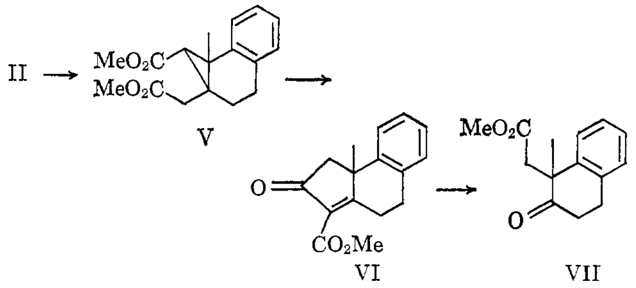
Stereospecific Rearrangement of an Excited Triplet Ketone[1]

Sir:

Various attempts have been made to rationalize the photochemical rearrangements of conjugated cyclohexenones.[2-4] Among these attempts, it has been suggested[2] that the rearrangements observed can be accounted for on the basis of homolytic fission of the 1,10 bond (steroid numbering) with concomitant formation of a 5,10 double bond (giving an intermediate such as III) followed by readdition at C-5 and cyclization. This view suggests that for a cyclic enone (I) with a single suitably disposed asymmetric center, photorearrangement should give an optically inactive product. Alternate possibilities[3,4a] suggest retention of optical activity.



Irradiation (λ >290 mμ) of I in *t*-butyl alcohol gives II [70%; mp 86–87°; 5.82 and 1.65 μ; $\lambda_{max}^{95\%\ EtOH}$ 238 mμ (ε 9380)] and IV [1.5%; 5.73, 6.15, and 11.15 μ; $\lambda_{max}^{95\%\ EtOH}$ 245 mμ (ε 10,900) and 282 mμ (ε 1200), τ 4.56 and 5.12 (1 H, singlets, C=CH$_2$)].[5] Irradiation of II in *t*-butyl alcohol gives IV as does acid treatment of II. The structures of II and IV were established by degradation to known compounds. Treatment of II with ethyl formate and base followed by hydrogen peroxide oxidation and treatment with diazomethane gave V [5.75 and 5.80 μ; λ_{max}^{MeOH} 228 mμ (ε 8650)]. Treatment of V with sodium methoxide gave VI [5.75 and 6.15 μ; $\lambda_{max}^{95\%\ EtOH}$ 233 mμ (ε 10,300)]. Ozonolysis of VI followed by treatment with hydrogen peroxide and diazomethane gave VII, identical in infrared absorption, v.p.c. retention time, and 2,4-dinitrophenylhydrazone with an authentic sample.[6]



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(1) (a) Portions of this work were described at the Reaction Mechanisms Conference, Corvallis, Ore., June 1964. (b) Related work on the same system is being published simultaneously (H. E. Zimmerman, R. G. Lewis, J. J. McCullough, A. Padwa, S. Staley, and M. Semmelhack, *J. Am. Chem. Soc.*, **88**, 159 (1966).

(2) H. E. Zimmerman, *Advan. Photochem.*, **1**, 183 (1963).

(3) H. E. Zimmerman and J. W. Wilson, *J. Am. Chem. Soc.*, **86**, 4036 (1964).

(4) (a) O. L. Chapman, T. A. Rettig, A. A. Griswold, A. I. Dutton, and P. Fitton, *Tetrahedron Letters*, No. **29**, 2049 (1963); (b) W. W. Kwie, B. A. Shoulders, and P. D. Gardner, *J. Am. Chem. Soc.*, **84**, 2268 (1962); (c) B. Nann, D. Gravel, R. Schorta, H. Wehrli, K. Schaffner, and O. Jeger, *Helv. Chim. Acta*, **46**, 2473 (1963); (d) O. Jeger and K. Schaffner, *Chem. Weekblad*, **60**, 389 (1964); (e) O. Jeger, *Angew. Chem. Intern. Ed. Engl.*, **3**, 318 (1964); (f) O. Jeger, *Angew. Chem.*, **76**, 275 (1964).

(5) Satisfactory analyses were obtained for all new compounds except VI and IV (crystalline derivatives of IV were analyzed).

(6) Prepared by treatment of 1-methyl-2-tetralone with sodium hydride and methyl bromoacetate.