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THE PHOTOADDITION OF 2-CYCLOPENTENONE TO CYCLOHEPTENE; POTENTIAL PRECURSORS FOR TRICYCLO $[7.3.0.0^{2,8}]$DODECAHEXAENE (ZURLENE)

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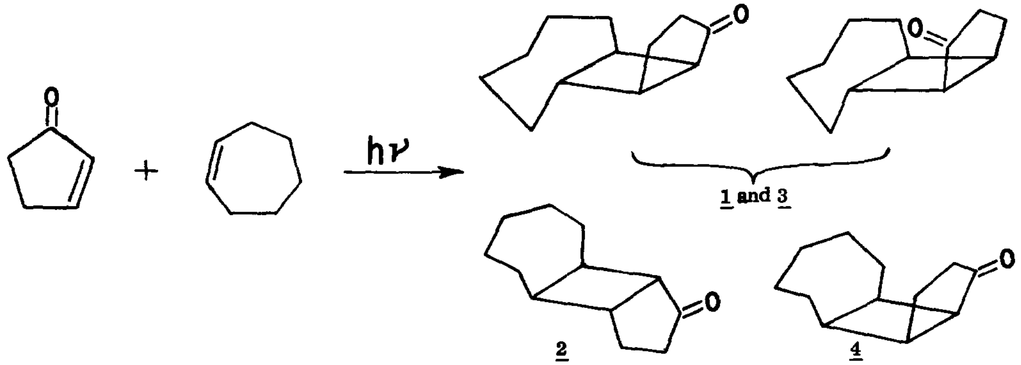
In connection with our continuing studies on the synthesis of nonbenzenoid aromatic systems incorporating small-rings we have studied the crossed photocycloaddition of 2-cyclopentenone to cycloheptene.[4] The photoinduced cycloaddition of simple alicyclic enones to cyclic and acyclic alkenes is a reaction of broad synthetic utility and the mechanism of this reaction has attracted widespread interest.[5] It is generally assumed that the new carbon carbon bonds are formed in a sequential rather than concerted fashion. This contention is supported by Corey's observation that stereochemical integrity is not maintained and the same mixture of photoadducts is obtained with cyclohexenone regardless of whether *cis* or *trans*-2-butene is used as a substrate.[5d] By implication the two reactions proceed through a discrete and common intermediate since the intervention of excited alkenes in such cycloaddition reactions is improbable. Furthermore it has been argued that development of a *trans* fusion in that portion of an adduct arising from a *cis* cycloalkene is diagnostic of a stepwise cyclization process, although few examples of such reactions have been reported to date.[5e, f, g] At this time we wish to report our results on the photoaddition of cyclopentenone to cycloheptene where it has been found that substantial amounts of the two isomers with the seven-membered ring fused *trans* to the four-membered ring are formed.



Four isomeric 2-cyclopentenone-cycloheptene adducts are obtained when 2-cyclopentenone is irradiated[6a] in neat cycloheptene and may be separated on a preparative scale by glpc [column (b) or (c)]

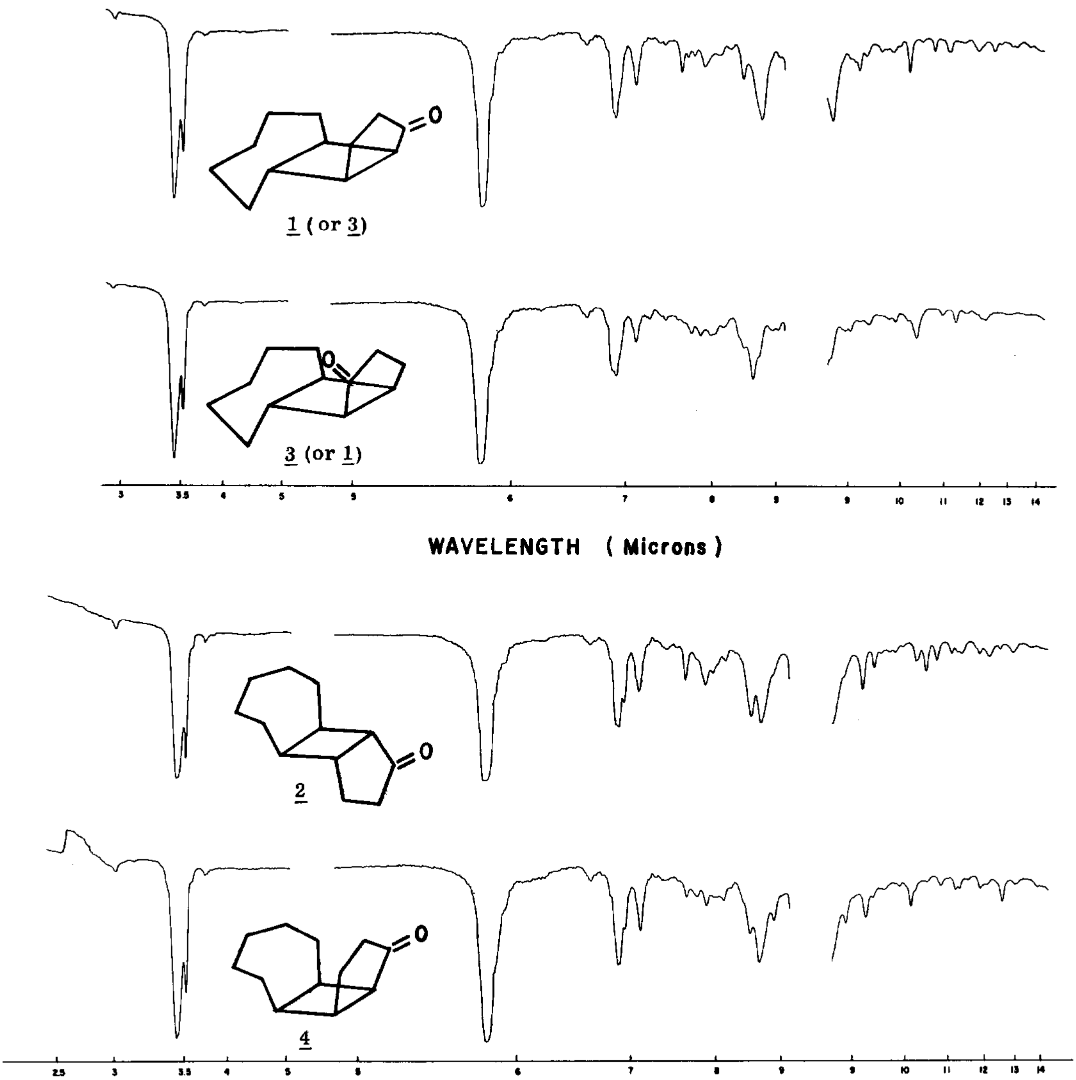


FIGURE I

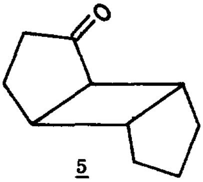
The infrared spectra of 1-4 were determined neat on a Beckman-IR 7 spectrophotometer. The sample of 1 contained 6% of isomer 2 and 7% impurities; 2 contained 4% of isomer 1; isomer 3 contained 5% of isomer 2; 4 contained 5.5% of isomer 3 and 5% of isomer 2.

The relative amounts of 1, 2, 3 and 4 (numbered in order of their emergence from the columns) are 4.0: 22: 6.7: 1.0, respectively. For purposes of comparison and identification the infrared spectra of the four ketones are recorded in figure I.[6b] That the ketones 1-4 are isomeric was established by mass spectroscopy (m/e=178).[6c] The absence of signals in the vinyl proton region of the nmr spectra

(220 mHz)[6d] when coupled with the infrared data (nonconjugated C=O) attests to the presence of the cyclobutane ring in all four isomers.

The *trans* 7-4 fused tricyclo[7.3.0.0^{2,8}]dodecanones 1 and 3 were easily identified since they afford the same tricyclic hydrocarbon upon Wolff-Kishner reduction. The reduction products from 1 and 3 were shown to be identical by glpc enhancement techniques [columns (d) and (e)][7] under conditions where the corresponding reduction products of 2 and 4 can be separated. Their infrared spectra are also identical and are reassuringly different from the infrared spectrum of the reduction product of 2, the major product. At this stage it remained to differentiate 1 from 3 and to determine which member of the remaining isomeric pair, namely 2 and 4, has *cis*, *trans*, *cis* and which "*all cis*" stereochemistry.

We have resolved the latter and more complex of these stereochemical problems and demonstrated that 2 has *cis*, *trans*, *cis* stereochemistry by indirectly correlating its structure with that of tricyclo [5.3.0.0^{2,6}]decanone-3 (5) an adduct of 2-cyclopentenone and cyclopentene.[5a] The structure of 5 had been related to the cyclopentenone dimers 6 and 7 by Eaton[8] through reduction to a common hydrocarbon. In turn the dimers 6 and 7 were converted to *cis*, *trans*, *cis*-1,2,3,4-tetracarbomethoxycyclobutane (8) the structure of which had been established without ambiguity in our laboratories.[9] With the structure of 2 confidently established we were safe in assuming that the remaining 2-cyclopentenone cycloheptene adduct, formed in lowest yield, has the "*all cis*" structure 4.[10]



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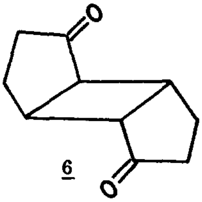

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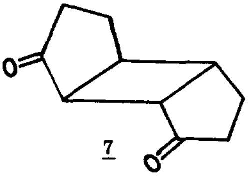

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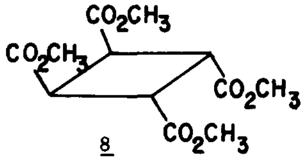

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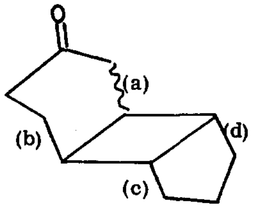

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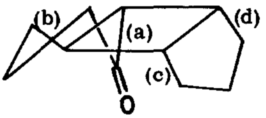
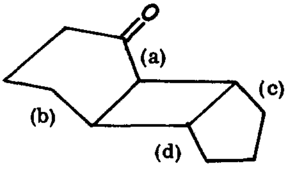


10a

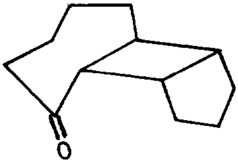


10b

The correlation of 2 with 5 was accomplished in the following manner: addition of a two molar excess of diazomethane to 5 in the presence of boron trifluoride etherate[11a] gave a homologous ketone 9 which was isolated by glpc [column (a)].[6a] The expanded ketone 9 while isomeric (m/e=164) is not identical to either of the photoadducts 10 of 2-cyclohexenone and cyclopentene obtained earlier by Corey and co-workers and in the absence of definitive data assigned structures 10a and 10b by analogy with related reactions.[5d] While 9 differs from 10a and 10b the hydrocarbon obtained as the major product on reduction of 9 is identical to that obtained on reduction of the mixture of photoadducts 10. It was established by Corey that either 10a or 10b, probably the former with the *trans* 6-4 fused ring juncture and presumably the less stable isomer is epimerized to the alternate isomer upon treatment with alumina.[5d] Isomerization also occurs under the basic Wolff-Kishner conditions and explains why a single product is obtained upon reduction of mixtures of 10a and 10b. It may be concluded from these data that the diazomethane homologization of 5 occurs with introduction of the methylene group between the carbonyl group and the cyclobutane ring to give 9. Of course bonds (b), (c) and (d) are unaltered by conversion of 5 to 9 and thus the stereochemistry at these sites must be the same in 5 and 9 as well as in 10a and 10b.

While we write the geometry of bond (a), the site of "insertion", in an ambiguous manner it is known that the diazoalkane-carbonyl reaction proceeds with retention of configuration,[11b] and therefore the implied *cis, trans, cis* stereochemistry of ketone 9 is undoubtedly correct. The stereochemistry of bonds (b), (c) and (d) in 10a and 10b has been defined and certainly the assumption that 10b is more stable than 10a is valid. Thus the complete structures of the major (more stable) and minor photoadducts of 2-cyclohexenone and cyclopentene isolated by Corey are established.[13] Our conclusions corroborate Corey's original proposal regarding the structures of these products .[5d] In any case the validity of our subsequent stereochemical arguments regarding the structures of 2 and 4 is not contingent upon any of the assumptions regarding the stereochemistry of bond (a) in 9, 10a or 10b.

Clearly the orientation of bonds (b), (c) and (d) in the Corey ketones 10 precludes formation of an "*all cis*" fused [7.3.0.0^{2,8}]tricyclic system from 10 (either 10a or 10b) by diazomethane homologization regardless of the position of "insertion" or stereochemistry of the process. More specifically



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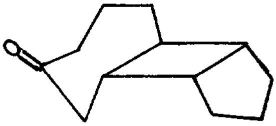

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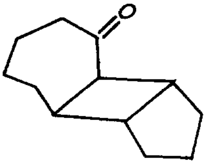

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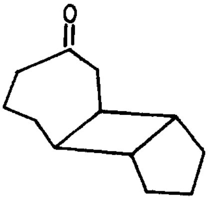

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only four C$_{12}$-homologs may be formed upon treatment of the C$_{11}$-ketones 10 with diazomethane, namely 11, 12, 13 and 14. It was established by glpc [columns (a), (d) and (e)] that one *major* product is formed upon treatment of homogeneous samples of 10b provided limited amounts of diazomethane and catalytic amounts of aluminum chloride are used.[11c] This compound while not characterized completely was shown to have the desired molecular weight (m/e 178) and upon reduction gave a hydrocarbon (m/e 164) which is different [columns (d), (e) and (f)][7] from that obtained from ketones 1 and 3; however, infrared and glpc data [columns (d) and (e)][7] confirm that this product is identical to the hydrocarbon obtained from 2. It follows that 2 must have the cis, trans, cis stereochemistry and that 4, the photoadduct obtained in lowest yield from 2-cyclopentenone and cycloheptene must be the cis, cis, cis isomer. Except for the distinction between the structures 1 and 3, the stereochemistry of the cycloaddition 1-4 is then defined.

The expanded ketone obtained from 10 cannot have structure 12 since reduction would lead to the same trans 7-4 fused hydrocarbon obtained from 1 and 3. In contrast 11 could epimerize and give the observed cis, trans, cis tricyclic hydrocarbon and therefore cannot be rigorously excluded; however this alternative is unlikely since 11 could only be formed by homologization of what certainly is the less stable epimer (10a) and the more stable epimer 10b was employed. Of the remaining structures 13 and 14 for the expanded ketone obtained from 10b, the latter appears more reasonable on the basis of experience gained in the conversion of 5 to 9. It should be noted that these speculations with regard to the structure of the homologization product obtained from 10 have no bearing on the validity of our previous stereochemical arguments.

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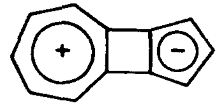
1. Recipient of a Fellowship from Stiftung fur Stipendien auf dem Gebiete der Chemie, Basel, Switzerland
2. Abstracted in part from the dissertation of R. A. Mateer (NASA Fellow 1964-1966) submitted in partial fulfillment of the Doctor of Philosophy degree at Tulane University, New Orleans, Louisiana; See Dissertation Abstr., 27, No.10, 3461-b (1967). Support of this work by grants (GP 2543 and 6420) from the National Science Foundation is gratefully acknowledged.
3. Author to whom inquiries regarding this paper should be addressed.
4. This investigation is part of a general program directed toward the synthesis of the unknown nonbenzenoid hydrocarbon tricyclo [7.3.0.0^{2,8}]dodecahexaene (15) for which we suggest the trivial name "Zurlene" for reasons which need not be explicated here. See H. S. Lee, Chemistry (The Chinese Chem. Soc., Taiwan, China) 53 (1963) for molecular orbital calculations on 15. The calculated delocalization energy (4.2β) is in agreement with the value obtained by H. E. Simmons (personal communication). A discussion of 15 is included in a recent review on nonalternant hydrocarbons. See R. Zahradnik, Angew. Chem., 77, 1097 (1965).



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6. (a) All irradiations were conducted at -78° using a Pyrex filter and a Hanovia 450 W high-pressure mercury lamp (Type 79A36). A reaction vessel (700 ml) incorporating the Hershberg circulating

principle was used and equipped with a standard Hanovia water-cooled quartz probe. Highest yields of 1-4 as well as 10a and 10b (80-85%) were obtained when 15 ml of the ketone and 400 ml of cycloalkene were irradiated for a period of 6 hours.

(b) Infrared spectra were recorded on a Beckman-IR 7 spectrophotometer.

(c) We wish to thank Mr. R. L. Smith for technical assistance in obtaining mass spectral data on a Hitachi Perkin-Elmer RMU-6E mass spectrometer.

(d) We are indebted to Professor Norman S. Bhacca for 100 and 220 mHz nmr spectral determinations on ketones 1-4. A collaborative C^{13} nmr spectral study of these ketones is in progress.

(e) Sufficient quantities of the new products 2 and 9 were available to obtain satisfactory combustion analyses on each as well as the o-bromobenzhydrazone (mp 199-201°) of 2.

7. Preparative glpc separations were achieved using 3m x 8 mm O. D. glass columns packed with (a) 25% DC-Hyvac grease on Chromosorb P (220°) or alternatively on 12 ft x 3/8 in Aerograph Autoprep aluminum columns packed with either (b) DC-Hyvac on Chromosorb P (245°) or (c) DC-550 on Chromosorb P (225-30°). Homogeneity and enhancement studies were conducted on a Perkin-Elmer 810 gas chromatograph equipped with a flame-ionization detector. Satisfactory resolution was obtained on the following support-coated open-tubular (SCOT) columns: (d) Carbowax 20 M (175°), (e) Silicone DC-550 (160°) and (f) Apiezon L (150°). In those cases where enhancement techniques were used to confirm the identity of a compound two separate columns were invariably employed under conditions where the other isomeric members of the series could be resolved.

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10. Implicit in our stereochemical arguments is the assumption that the ring fusion at the juncture of the four- and five-membered rings has cis stereochemistry in the adducts 1, 2, 3, 4, 10a and 10b. Examples of 5-4 trans fused bicyclic systems are known[12] and while our data do not exclude initial formation of a photoadduct incorporating such a trans fused juncture in the keto ring of 1, 2, 3 and 4 it is improbable in view of the inherent strain and lability of the 3°-hydrogen adjacent to the carbonyl group that a trans 5-4 adduct related to 5 would survive work-up without isomerization to the cis fused epimer, even if formed. Furthermore, in view of the strain involved it does not seem probable that a trans 5-4 juncture would develop at the site of fusion in 10a and 10b where cyclopentene is the substrate and this presumption is supported by the work of Eaton on 5.

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13. Using capillary glpc columns of the Perkin-Elmer SCOT columns (d), (e) and (f)[7] we were successful in detecting four isomeric cyclohexenone-cyclopentene adducts A, B, C and D. The isomer A which emerges first from the column, a minor product, upon treatment with alumina is converted to the major photoadduct B and the second to emerge. The third and minor component C, under similar equilibrating conditions, is converted to the fourth photoproduct D, produced in about the same amount as A and C, which has the longest retention time. It is clear that A and B are the adducts 10a and 10b, respectively, reported earlier by Corey.[5d] From the equilibration data we assume D has cis, cis, cis stereochemistry and C, like 10a has a trans 6-4 fusion, but with the carbonyl group trans to the 5-membered ring.