

STEROID PHOTOCHEMISTRY. A PHOTO-DIELS-ALDER
REACTION IN ENONE CYCLOADDITIONS.

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Although the photo-Diels-Alder reaction is well known,¹ the use of enones, the mainstay of the thermal reaction, has been virtually nonexistent. In the few cases where enone-diene cycloadditions have been investigated, the predominant reaction occurs through the singlet state and leads to cis-[2+2]-cycloaddition with small amounts of cis-[4+2]-adducts as by-products.² We would like to present evidence that the photocycloaddition of linear steroidal 3-keto-4,6-dienes to linear 1,3-dienes is a genuine photo-Diels-Alder reaction, obeying orbital symmetry rules and proceeding from the triplet state. We had previously described the products from the photocycloaddition of Δ^6 -testosterone acetate **1** to butadiene and had shown that the predominant product was the trans-fused [4+2]-adduct **3**, mp 223-5° C, which could be epimerized to the cis-fused 4 β ,5 β -isomer **4**, mp 127-9° C.³ This reaction has been extended to a series of Diels-Alder dienes (Table).^{4,5} The isolation of the trans-4 α ,5 β -[4+2]-adduct **3c**, mp 206-8° C, confirmed the initial results with butadiene when the NMR spectrum showed the vinyl methyl groups as a broad singlet at 1.63 δ . These trans-adducts are much less stable than the equivalent trans-4 α ,5 β -[2+2]-adducts,⁶ and were always accompanied by their 4 β ,5 β -cis-epimer **4**. Since the predominant, if not exclusive, cis-addition of olefins and dienes to steroids occurs from the α -side, these epimers are not photoproducts but are derived from **3**.^{4,6,7} The derived isoprene adducts were identified as a separable equimolar mixture of the cis-4 β ,5 β -[4+2]-epimers **4b**, mp 209-11°C (R₃=H, R₄=CH₃) and 269-70°C (R₃=CH₃, R₄=H), although a small amount of one of the trans-isomers **3b** (R₃=H, R₄=CH₃), mp 175.5-79°C, was isolated.^{8,9}

Irradiation of **1** with 1-acetoxybutadiene gave the epimeric trans-adduct **3d**, mp 206-7°C (R₅=OAc, R₆=H) and mp 209-11°C (R₅=H, R₆=OAc).¹⁰ Saponification and Jones oxidation¹¹ gave the diene-trione **5**, mp 236-8°C. Equivalent results were obtained in the

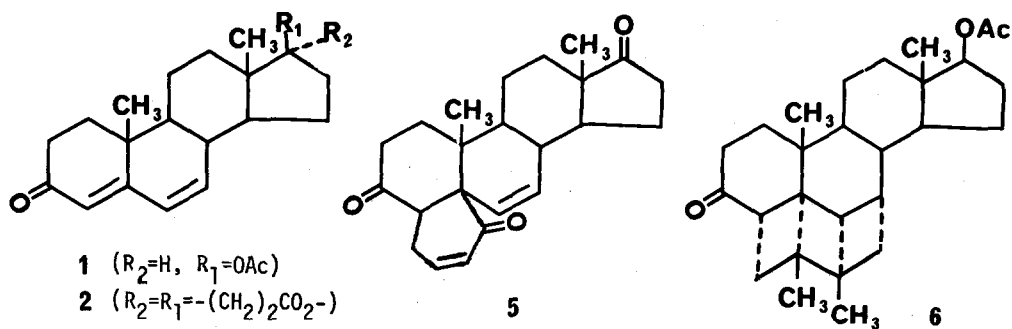
photocycloaddition of 2 to s-cis-2,4-dimethyl-1,3-pentadiene to form 3e, mp 275-7°C (4 β -H, quartet, δ 3.12), indicating regio and stereospecific formation of head-to-tail trans-[4+2]-adducts.

Photochemically produced ground state trans-enones¹² undergo: [4+2]-cycloaddition with dienes, particularly furan and cyclopentadiene; possess stability at low temperatures; add hydroxylic solvents and dimerize.¹³ Although the triplet state of these enones is higher than the dienes, internal conversion to the trans-ground state is considered to be much faster than inter-molecular energy transfer.^{12d} Obviously both the photo-Diels-Alder reaction and the thermal Diels-Alder from the trans-enone form the same trans-[4+2]-adduct. To differentiate between these two reaction pathways, we have examined the dienone-diene cycloadditions under the above conditions. Attempted trapping of a trans-intermediate at -78°C, with 2,3-dimethylbutadiene, using the ladder compound 6, a non-crystalline glass,¹⁴ as an indicator of a photo-reaction, was expectedly negative. The irradiation of 1 in methanol did not form any methoxyl adducts and the addition of diene resulted in the usual adducts. Although the trapping of trans-enones with furan is exceedingly facile, irradiation of 1 or 2 in the presence of either furan or 2,5-dimethylfuran did not result in any cycloaddition and dienone was recovered.¹⁵

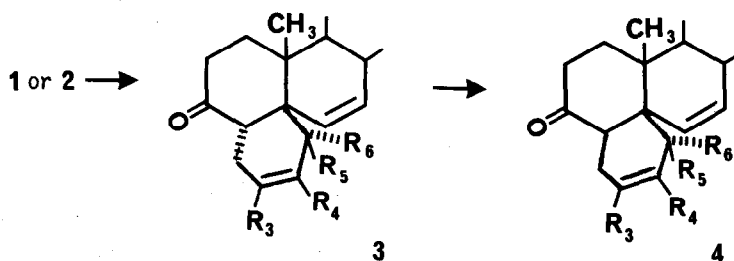
Since the $\pi\pi^*$ -triplet of the dienone 1 should be lower than the dienes studied¹⁶ and the near accidental degeneracy of the $n\pi^*$ and $\pi\pi^*$ -triplets removed by the second double bond,¹⁷ quenching studies were attempted with Ullman's quencher, 3,3,4,4-tetramethyl-1,2-diazetidene 1,2-dioxide.¹⁸ Quenching of the photocycloaddition of 2 to dimethylbutadiene was readily accomplished using this quencher, implicating the $\pi\pi^*$ -triplet of the dienone as the reactive species. The slight twisting in C4,5-double bond in the $\pi\pi^*$ -triplet of the dienone,^{17,19} facilitates the allowed [4s+2a]-cycloaddition to form the observed trans-4 α ,5 β -Diels-Alder adduct. As the reaction proceeds through the triplet, it appears that bond formation in the adduct is occurring simultaneously with spin inversion. If the reaction was occurring through a tetramethylene, radically different products would be observed.^{2,4}

References

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4. Photocycloadditions to non-Diels-Alder 1,3-dienes have also been described: G. R. Lenz, Tetrahedron, 31, 1587 (1975).
5. Proper microanalytical and spectral data (IR, UV, NMR, MS, ORD, and CD) have been obtained for all new compounds described herein.



Table



<u>Diene</u>	<u>Dienone</u>	<u>R₃</u>	<u>R₄</u>	<u>R₅</u>	<u>R₆</u>	<u>Yield*</u>
a. butadiene	1	H	H	H	H	50%
b. isoprene	2	H	CH ₃	H	H	40%
c. 2,3-dimethylbutadiene	1	CH ₃	CH ₃	H	H	42%
d. 1-acetoxybutadiene	1	H	H	OAc	H	49%
e. 2,4-dimethyl-1,3-pentadiene	2	CH ₃	H	CH ₃	CH ₃	24%

*The yield was the total of the isolated 3 and 4, the remainder being ladder compounds 6, 6,7-cis-[4+2]-adducts and recovered diene.

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9. With isoprene only, a small amount of a cis-[2+2]-adduct was isolated. Intensive reinvestigation of the butadiene and 2,3-dimethylbutadiene reactions failed to reveal any evidence for [2+2]-adducts.
10. The epimer structures were determined using the dihedral angle dependence of the allylic coupling constant [G. V. Smith and H. Kriloff, J. Amer. Chem. Soc., 85, 2017 (1963)], and the appearance of the C β -H as quartets at δ 3.37 and 3.13, respectively.
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14. The 17 β -hydroxy derivative of 6 is a crystalline solid, mp 138-140°C. Reacetylation of the thrice recrystallized sample of the alcohol returned 6 still as a non-crystalline glass.
15. Apparently the lowest triplet of furan is unknown [R. Srinivasan, Pure Appl. Chem., 16, 65 (1968)], although it is conceivable that it could be acting as a triplet quencher of 1 or 2 if it is considered as a cis-terminally oxygen substituted diene. This would then agree with ref. 12d where enone triplets convert to trans-enones faster than energy transfer occurs. Alternatively it could be quenching the singlet state of the dienone, but then the excited trans-enone precursor(s) would also be expected to be quenched.
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