group is preferred from the apical site, we postulate that formation of dipole **5P** should also be kinetically preferred.

The mechanistic significance of the present study is that (a) the HGA-type and CGA-type dipoles **5** and **6** do lead to characteristic chemical transformations and (b) such intermediates do not interconvert via phosphorane **7**.

Acknowledgments are made to the Deutsche Forschungsgemeinschaft, the Fonds der Chemischen Industrie and the Humboldt Foundation for financial support.

Registry No. **1a**, 594-88-7; **1b**, 40157-11-7; **1c**, 40157-10-6; **2a**, 10008-69-2; **2b**, 35947-72-9; **2c**, 35947-73-0; **3a**, 563-79-1; **3b**, 24274-73-5; **3c**, 35947-82-1; **4a**, 23438-10-0; **4b**, 35394-04-8; **4c**, 35394-03-7; ethyl azocarboxylate, 1972-28-7; methyl azocarboxylate, 2446-84-6; triphenylphosphine, 603-35-0; acetone, 67-64-1; 1,2-diphenylethanone, 451-40-1.

[(4 + 2) + (3 + 2)] Route to Multiply Fused Ring Systems: A New Notion in Polycycle Construction

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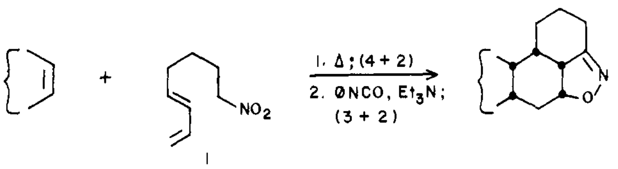
The construction of multiply fused carbocyclic systems has long commanded the attention of synthetic organic chemists. One need only trace the lengthy history associated with the production of steroids and steroid-like compounds to realize the veracity of such a statement. The primary ring-forming methodologies that have emerged as a consequence of the steroid efforts consist of (a) Friedel–Crafts type acylation reactions, (b) the Dieckmann condensation, (c) the Robinson annelation process, and (d) the Diels–Alder reaction.[1] Of course, these same methods have been used in generating the ring skeleton of non-steroid products as well.

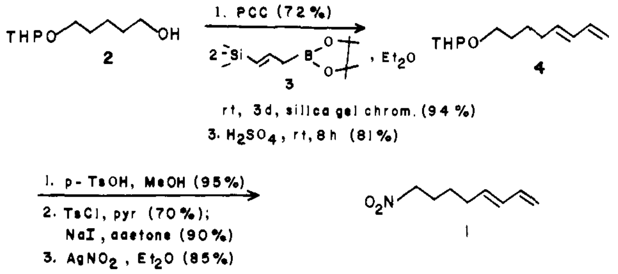
We would now like to introduce a new notion into the area of carbocycle synthesis, a notion that as diagrammed in Scheme I provides the chemist with a method for annealing three new rings (one being a heterocycle) to an existing ring structure so as to produce a tetracycle possessing five new precisely defined centers of asymmetry. The stereochemistry of the (4 + 2) cycloaddition process is controlled, of course, by secondary orbital interactions (Alder endo rule)[2] while that of the (3 + 2) reaction would seemingly be guided by the tendency to minimize nonbonded interactions in the transition state; i.e., the nitro group derived nitrile oxide would add to that face of the olefin that bears the nitrobutyl chain.[3] The isoxazoline ring generated in this process does further provide a versatile and easily manipulable functional array.[4]

The realization of the concept displayed in Scheme I requires only that we be able to prepare the nitro diene **1** in some reasonable manner. We have at present been able to generate the stereochemically pure (>97% by ^1H NMR analysis) (*E*)-diene **4** by reaction of Matteson's allyl boronate reagent **3**[5] with the aldehyde prepared by oxidation of the mono-THP ether **2** of 1,5-pentanediol. The THP group of **4** is then cleaved and the hydroxyl group transformed to nitro by the three-step sequence shown (Scheme II).

Scheme I



Scheme II



To test the capability of this new diene for effecting the triannelation sequence, we studied its chemistry using first *p*-benzoquinone as the dienophile. The Diels–Alder reaction proceeded at 110 °C in toluene to provide **5** as an unstable oil. Since this intermediate was found to tautomerize on silica gel chromatography giving rise to **6a**, **5** was directly acetylated, and the dipolar cycloaddition reaction was then carried out. The crystalline tetracycle **7** (mp 109–110 °C, ethyl acetate–hexanes) was formed in high yield. In order to prevent the foregoing tautomerization process, the reaction of **1** with carbomethoxy-*p*-benzoquinone[6] was studied next. The primary Diels–Alder product formed in this case was found to undergo epimerization at C-5 during silica gel chromatography (trans/cis isomer ratio 95:5). Intermediate **8** provides an interesting substrate for the intramolecular nitrile oxide cycloaddition (INOC) reaction since it offers two very different sites for capture of the nitrile oxide. In the event, exposure of **8** to *p*-chlorophenyl isocyanate provided solely the bridged structure **9** (mp 147–148.5 °C, ethyl acetate–hexanes). The formation of an eight-membered ring in preference to a less strained six-membered ring presumably reflects the heightened reactivity of the C_2–C_3 double bond (i.e., the increased π-electron polarizability of the multiple bond).[7] The unexpected course of this cycloaddition reaction is not without some interest, especially if one recognizes the skeletal relationship of **9** to the taxanes.[8]

To steer the INOC reaction in the direction of the angularly fused system, removal of the more reactive double bond was required. Compound **8** was exposed to L-Selectride (Aldrich) and then the dipolar cycloaddition process carried out. The tetracycle **10** (mp 234–236 °C, ethyl acetate–hexanes) was thus formed in good overall yield. This particular synthesis of an angularly fused ring system holds considerable potential for the development of a unique route to the antileukemic principles, the quassinoids,[9] for the isoxazoline ring could be turned into the required δ-lactone subunit present in these natural products in a fairly straightforward fashion (Scheme III).

The assignment of stereochemistry to all of the products described in this paper was made on the basis of extensive ^1H NMR spin–spin decoupling experiments. Since some of the coupling constants observed were slightly larger than one normally finds in related six-membered ring fused compounds[10] (see ref 11), a

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[§] Veterans Administration Medical Center.

(1) Akhrem, A. A.; Titov, Yu. A. "Total Steroid Synthesis"; Plenum Press: New York, 1970.

(2) Sauer, J. *Angew. Chem., Int. Ed. Engl.* **1967**, *6*, 16.

(3) For an example of such stereocontrol in the formation of a seven-membered ring, see: Kozikowski, A. P.; Mugrage, B. B. *Tetrahedron Lett.* **1983**, *24*, 3705.

(4) Kozikowski, A. P. *Acc. Chem. Res.*, submitted for publication.

(5) Tsai, D. J. S.; Matteson, D. S. *Tetrahedron Lett.* **1981**, *22*, 2751.

(6) Goldsmith, D. J.; Srouji, G.; Kwong, C. *J. Org. Chem.* **1978**, *43*, 3182. The reaction of carbomethoxy-*p*-benzoquinone with 1-vinylcyclohexene provides a less functionalized analogue of **10**: Orsini, F.; Pelizzoni, F.; Pitea, D.; Abbondanti, E; Mugnoli, A. *J. Org. Chem.* **1983**, **48**, 2866.

(7) Huisgen, R. *Angew. Chem., Int. Ed. Engl.* **1963**, *2*, 633.

(8) Miller, R. W. *J. Nat. Prod.* **1980**, *43*, 425.

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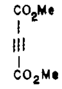
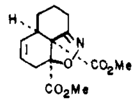
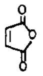
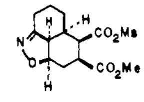
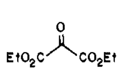
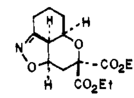
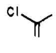
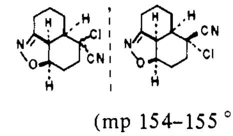
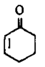
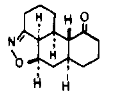
0002-7863/84/1506-1845$01.50/0

Table I. Other Examples of the [(4 + 2) + (3 + 2)] Triannelation Process

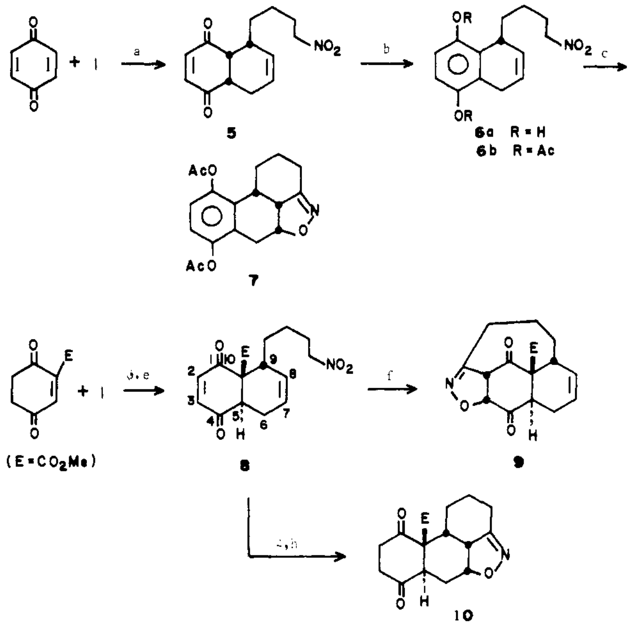
entry	dienophile	(4 + 2) reaction conditions	yield, %[b]	(3 + 2) product[a]	yield, %[b]
1		110 °C, toluene, 15 h	60		51
2		110 °C, toluene, 15 h; 100%; MeOH, Δ and CH_2N_2	91[c]	 (mp 124-125 °C, ethyl acetate-hexanes)	85
3		110 °C, toluene, 15 h	60		88
4		110 °C, toluene, 15 h	73	 (mp 154-155 °C, ether-hexanes)	71[d]
5		70 °C, $AlCl_3$, toluene, 19 h	52	 (mp 117-119 °C, CCl_4-hexanes)	67[e]

[a] The (3 + 2) reactions conditions consisted in all cases of heating with phenyl isocyanate/triethylamine in refluxing benzene for ~15 h. [b] The yields reported are for the isolated products (silica gel chromatography or recrystallization); since no attempt has been made to optimize the reaction conditions, these numbers should be considered as representative of minimal values. [c] The anhydride was converted to the diester in order to facilitate purification and handling of intermediates. [d] A 3:1 mixture of products is formed in the Diels-Alder reaction in which the cyano group of the major product is syn to the nitrobutyl appendage. This is in accord with the Alder endo rule. The (3 + 2) reaction was carried out using the mixture. An attempt to convert the α-chloronitrile to ketone resulted in dehydrohalogenation to the unsaturated nitrile with loss of the ring-fusion hydrogen (mp 64-65.5 °C, ethyl acetate-hexanes). [e] Epimerization of the stereocenter α to the carbonyl group occurs at the Diels-Alder stage.

single-crystal X-ray analysis was carried out on **10**.[12] This analysis revealed that the five centers of asymmetry produced in the [(4 + 2) + (3 + 2)] process are perfectly in accord with the notions outlined earlier.

Other examples of the [(4 + 2) + (3 + 2)] cycloaddition methodology using **1** are displayed in Table I. It is of interest to note that while the (4 + 2) adduct formed from **1** and dimethyl acetylenedicarboxylate (entry 1) again presents two sites for reaction with the dipole, the more highly substituted, but more activated, double bond reacts exclusively. The third reveals the ability of **1** to react with a heteroatom dienophile,[13] thus providing access to a ring-fused pyran on dipolar cycloaddition. Only in entry 5 was the assistance of a Lewis-acid catalyst required to bring about the initial Diels-Alder reaction employing cyclohexenone as the dienophile.[14,15]

Scheme III



[a] (a) Toluene, 110 °C, 15 h (100%); (b) Ac_2O, pyr (70% isolated); (c) PhNCO, Et_3N, C_6H_6, ↑↓ 15 h (83% recrystallized); (d) C_6H_6, room temperature, 24 h; (e) silica gel (90% isolated); (f) ClPhNCO, Et_3N, C_6H_6, ↑↓ (58%); (g) L-selectride, THF, -78 °C (72%); (h) PhNCO, Et_3N, C_6H_6, ↑↓ 15 h (65% recrystallized).

In summation, we believe that the chemistry described in this communication provides an efficient means for gaining access to multiply fused ring systems in a stereospecific manner. The chemistry thus holds considerable potential for the construction of natural products of the quassin, steroid, anthracyclinone, di-

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(10) For comparison, see: Oppolzer, W. *Tetrahedron Lett.* **1970**, 3091.

(11) Spectral data for **10**: IR ($CHCl_3$) 1750, 1725 cm^{-1}, ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.67 (ddd, 1 H, J = 11.0, 5.1, 1.2 Hz), 3.72 (dd, 1 H, J = 11.0, 10.8 Hz), 3.66 (s, 3 H), 3.11-3.00 (m, 1 H), 3.04 (dd, 1 H, J = 12.1, 3.5 Hz), 2.93-2.65 (m, 5 H), 2.53-2.37 (m, 2 H), 2.06-1.90 (m, 1 H), 1.85-1.66 (m, 1 H), 1.47 (ddd, 1 H, J = 16.2, 12.1, 5.1 Hz), 1.38-1.13 (m, 2 H); mass spectrum (15 eV), m/z 305 (M^+). Exact mass calcd for $C_{16}H_{19}NO_5$: 305.1263. Found: 305.1264.

(12) Details of the X-ray structure are available as supplementary material.

(13) Ruden, R. S.; Bonjouklin, R. *J. Am. Chem. Soc.* **1975**, *97*, 6892.

(14) Fringuelli, F.; Pizzo, F.; Taticchi, A.; Wenkert, E. *J. Org. Chem.* **1983**, *48*, 2802.

(15) The product shown in entry 2 of the table was further converted in nearly quantitative yield to β-hydroxy ketone (mp 123-124 °C, ethyl acetate-hexanes) by Raney nickel/acetic acid hydrogenolysis.[16] Complete epimerization to the trans-fused decalin occurred under these conditions.

J. Am. Chem. Soc. **1984**, *106*, 1847-1848

terpenoid, and (hydronaphthalene) sesquiterpene type.

Acknowledgment. We are indebted to the Camille and Henry Dreyfus foundation (A.P. K.) and the Medical Research Service of the Veterans Administration Hospital (B.C.W.) for their support of these investigations.

Supplementary Material Available: Tables of the atomic positional and thermal parameters, bond distances, bond angles and structural figure for **10**, and the physical and spectral data for compounds **1**, **5**, **6b**, **7**, **8**, **9**, **10**, and entries 1–5 of Table I (11 pages). Ordering information is given on any current masthead page.

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(16) Wollenberg, R. H.; Goldstein, J. E. *Synthesis*, **1980**, 757.

Photochemical α-Hydride Abstraction

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The abstraction of α-hydrogens from transition-metal alkyl groups is an important process in organo-transition-metal chemistry, especially in view of the proven and implied activity of the generated alkylidene and alkylidyne functions in a number of catalytic and stoichiometric reactions.[1-5] We wish to communicate here our initial observations on the high yield and efficient photochemical generation of alkylidene groups in tantalum systems.[6,7] These results are important in that they represent the first unequivocal demonstration of photochemically induced α-hydride abstraction generating alkylidene groups that are thermally inaccessible. Furthermore the results also demonstrate the high activity of alkylidene functions for the activation of aliphatic CH bonds, an area of intense current interest.[8]

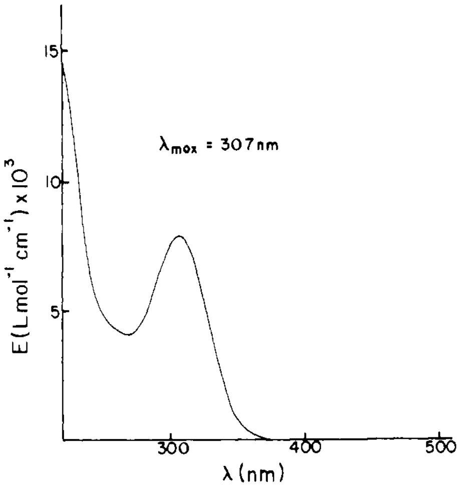
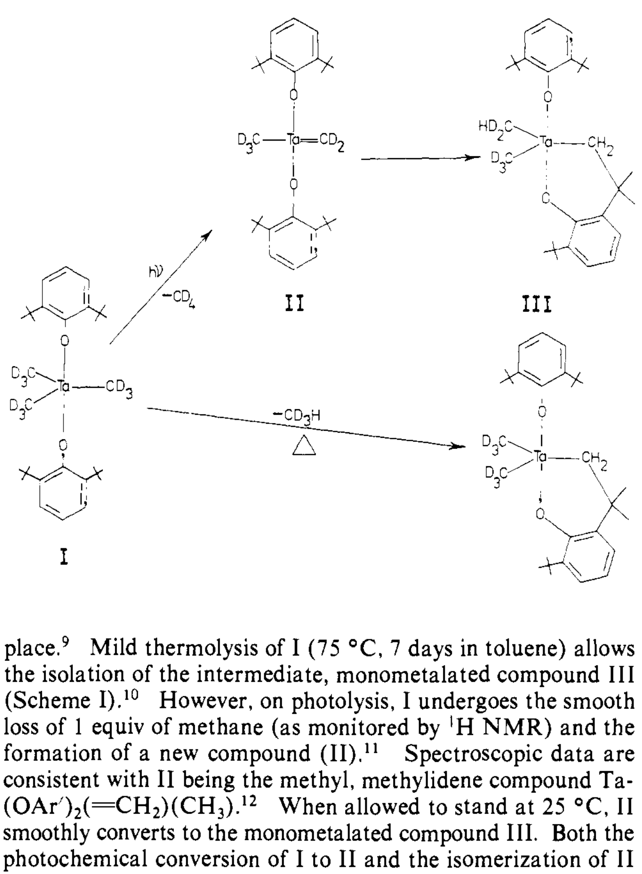


Figure 1. Absorption spectrum of Ta(OAr′)$_2$Me$_3$ in cyclohexane solvent.

Scheme I



We recently reported the metalation behavior of the compound Ta(OAr′)$_2$Me$_3$ (I) (OAr′ = 2,6-di-*tert*-butylphenoxide) in which on thermolysis at 120 °C loss of 2 equiv of methane and cyclometalation of a *tert*-butyl group in each aryl oxide ligand takes place.[9] Mild thermolysis of I (75 °C, 7 days in toluene) allows the isolation of the intermediate, monometalated compound III (Scheme I).[10] However, on photolysis, I undergoes the smooth loss of 1 equiv of methane (as monitored by ^{1}H NMR) and the formation of a new compound (II).[11] Spectroscopic data are consistent with II being the methyl, methylidene compound Ta(OAr′)$_2$(=CH$_2$)(CH$_3$).[12] When allowed to stand at 25 °C, II smoothly converts to the monometalated compound III. Both the photochemical conversion of I to II and the isomerization of II to III are essentially quantitative as determined by ^{1}H NMR. In order to prove that the thermal and photochemical routes to III are different, we performed a labeling study, the results of which

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(3) Grubbs, R. H. *Prog. Inorg. Chem.* **1978**, *24*, 1.

(4) (a) Ivin, K. J.; Rooney, J. J.; Stewart, D.; Green, M. L. H.; Mahtab, R. J. *J. Chem. Soc., Chem. Commun.* **1978**, 604. (b) Turner, H. W.; Schrock, R. R. *J. Am. Chem. Soc.* **1982**, *104*, 2331. (c) Mahmoud, K. A.; Rest, A. J.; Alt, H. G. *J. Chem. Soc., Chem. Commun.* **1983**, 1011.

(5) Hayes, J. C.; Pearson, G. D. N.; Cooper, N. J. *J. Am. Chem. Soc.*, **1981**, *103*, 4648.

(6) It has been mentioned that photolysis of Cp$_2$TaMe$_3$ can lead to the formation of Cp$_2$Ta(=CH$_2$)(CH$_3$), but experimental details were not reported.[2] The photochemistry of a number of group 4 and 5 (cyclopentadienyl) alkyl compounds has been extensively studied. No alkylidene compounds, however, were isolated. See: (a) Emad, A.; Rausch, M. D., *J. Organomet. Chem.* **1980**, *191*, 313. (b) Leeuwen, P. W. N. M.; Van der Heigden, H.,; Roobeck, C. F.; Frijns, J. H. G. *Ibid.* **1981**, *209*, 169. (c) Mintz, E. A.; Rausch, M. D. *Ibid.* **1979**, *171*, 345. (d) Rausch, M. D.; Boon, W. H.; Alt, H. G. *Ibid.* **1977**, *141*, 299.

(7) Photoinduced β-hydride abstraction has been documented. See: (a) Bruno, J. W.; Kalina, D. G.; Mintz, E. A.; Marks, T. J. *J. Am. Chem. Soc.* **1982**, *104*, 1860. (b) Kazlauskas, R. J.; Wrighton, M. S. *Ibid.* **1982**, *104*, 6005. (c) Alt, H. G.; Eichner, M. E. *Angew Chem., Int. Ed. Engl.* **1982**, *21*, 78.

(8) (a) Parshall, G. W. *Catalysis* **1977**, *1*, 335. (b) Webster, D. E. *Adv. Organomet. Chem.* **1977**, *15*, 147. (c) Shilov, A. E.; Shteinman, A. A. *Coord. Chem. Rev.* **1977**, *24*, 97. (d)Brookhart, M., Green, M. L. H. *J. Organomet. Chem.* **1983**, *250*, 395 and references therein.

(9) Chamberlain, L.; Keddington, J.; Huffman, J. C.; Rothwell, I. P. *Organometallics* **1982**, *1*, 1538.

(10) ^{1}H NMR (30 °C, toluene-d_8) δ 1.11 (s, Me$_2$), 1.38 (s, OC$_6$H$_3$-*t*-*Bu*$_2$), 1.61 (s, OC$_6$H$_3$-*t*-*Bu*CMe$_2$CH$_2$), 1.20 (s, OC$_6$H$_3$-*t*-BuC*Me*$_2$CH$_2$), 2.07 (s, OC$_6$H$_3$-*t*-BuCMe$_2$*CH*$_2$), 6.5–7.5 (m, OC$_6$H$_3$). The signal due to the TaMe groups was assigned by comparison with the deuterated compound.

(11) Photolysis was achieved by the use of a 450-W Ace-Hanovia medium-pressure Hg lamp housed in a cooled quartz jacket. Samples to be photolyzed (either ^{1}H NMR tube samples or bulk samples in Pyrex tubing) were immersed in cold, running water between 3 and 10 cm from the lamp. The 313-nm line of the Hg spectrum was isolated by the use of an interference filter purchased from Oriel Corp. Quantum efficiencies were determined in benzene by using the known *trans*-cis isomerization of stilbene; see ref 6e and: Lewis, F. D.; Johnson, D. E. *J. Photochem.* **1977**, *7*, 421.

(12) ^{1}H NMR (30 °C, C$_6$D$_6$) δ 1.20 (s, TaCH$_3$), 9.41 (s, Ta=CH$_2$), 1.47 (s, OC$_6$H$_3$-*t*-*Bu*); ^{13}C NMR δ −288 (Ta=CH$_2$).

0002-7863/84/1506-1847$01.50/0