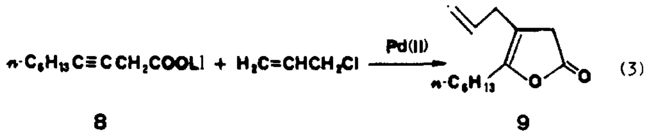
chloride afforded 3-allyl-3-decen-4-olide (**9**) in 85% yield by the cyclization of Endo-Dig manner (eq 3). Lithium 3-butynoate, however, did not give any allylated product.



The above described unsaturated lactones are useful intermediates for organic synthesis. Alkaline hydrolysis of (*E*)-4,7-octadien-4-olide gave 4-oxo-7-octenoic acid in 94% yield and other lactones shown in Table I afforded the corresponding keto acids in excellent yields. Diketones and heterocyclic compounds can be derived from the above lactones.

In summary we have shown unprecedented regio- and stereoselective synthesis of unsaturated lactones from lithium alkynoates by intramolecular oxypalladation affording alkenylpalladiums which couple with allyl or vinyl chloride stereospecifically.

Acknowledgment. This work was supported financially by the Ministry of Education, Science and Culture for Grant-in-Aid (59470081).

Steric Models for Stereoselectivity of Nitrile Oxide Cycloadditions to Chiral Alkenes

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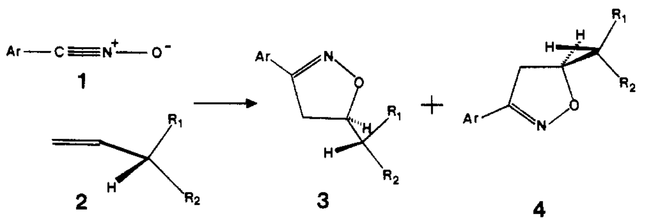
Received August 12, 1985
Revised Manuscript Received March 5, 1986

We have studied the cycloadditions of nitrile oxides to chiral alkenes, where the groups attached to the stereogenic center differ only in size. These cycloadditions occur preferentially on the face of the alkene that is more sterically shielded in the ground state. We propose a new transition-state model to account for stereoselectivities in this and related electrophilic cycloadditions and additions.[1]

The reactions of *p*-nitrobenzonitrile oxide, **1**, with various 3-substituted-1-butenes, **2**, give mixtures of diastereomers **3** and **4**.

Table I. Ratios of Isoxazoline Diastereomers from *p*-Nitrobenzonitrile Oxide Cycloadditions (25 °C, CH_2Cl_2)



3-R-1-butene		total	**3**:**4**	
R_1	R_2	yield (%)	exptl (±3%)	calcd[c]
a. Et	Me	72	50:50	50:50[d]
b. Ph	Me	70	59:41[a]	53:47[d]
c. *i*-Pr	Me	50	65:35[b]	72:28
d. $C(OMe)Me_2$	Me	93	80:20[a]	87:13[e]
e. *t*-Bu	Me	82	77:23[a]	97:3
f. Me	OMe	63	64:36[a]	68:32
g. Me	OPh-*p*-MeO	89	66:34[b]	
h. Me	OPh	93	60:40[b]	
i. Me	OPh-*p*-NO_2	91	60:40[b]	
j. *t*-Bu	OMe	64	>97:3[a]	96:4

[a] Structural assignments by X-ray crystallographic analysis carried out by Frank R. Fronczek at Louisiana State University or Jaime Abola and J. Mandel at the University of Pittsburgh. [b] Structural assignment based on vicinal coupling constants in the 300-MHz NMR spectrum. [c] From MM2 model calculations.[4] Ratios are obtained from Boltzmann distribution over the six staggered transition-state conformations. [d] Conformations with one group anti and one inside are essentially the same in energy as conformations with one group anti and one outside. [e] No lone pairs were included on the ether oxygen. With lone pairs included, a 96:4 ratio is predicted.

Product ratios were determined by NMR spectroscopy or HPLC analysis. Diastereomeric products were separated by column chromatography, and the structures were proven by X-ray crystallography or by NMR spectroscopy. Table I summarizes these and two previously reported results, entries f and j.[11] These reactions were also studied by an MM2 transition-state model,[2,3] the predictions of which are given in the last column of Table I.

In every case, the major product is that which would arise from attack of the nitrile oxide on the more hindered face of the preferred conformation of the isolated alkene,[4] and stereoselectivity increases as the size of R increases. We believe that the major product arises from the staggered[5] transition state, A, which has the largest group anti and the medium-sized group inside. The minor product arises from B. This model also rationalizes the stereoselectivities of nitrile oxide cycloadditions of allylic ethers, reported earlier, when M = alkoxy and L = alkyl.[1g-i] Entries f–i in Table I involve different alkoxy groups but give essentially identical product ratios. Previous studies by Jäger showed that similar stereoselectivities are observed for reactions of allylic ethers in which OR = OMe, OTHP, OAc, or $OSiR_3$.[1h,i] Thus, the "inside alkoxy effect", described earlier,[11] reinforces, rather than reverses, the purely steric effect which we have now found to favor A. An allylic oxygen avoids the anti position in order to minimize electron

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(1) Examples of models for electrophilic reactions not involving chelation of reagent with a substituent. (a) Alkylation and protonation of enolates: Fleming, I.; Lewis, J. J. *J. Chem. Soc., Chem. Commun.* **1985**, *149*. (b) McGarvey, G. J.; Williams, M. J. *J. Am. Chem. Soc.* **1985**, *107*, 1435. Osmium tetroxide hydroxylation: (c) Cha, J. K.; Christ, W. J.; Kishi, Y. *Tetrahedron* **1984**, *40*, 2247. (d) Stork, G.; Kahn, M. *Tetrahedron Lett.* **1984**, *24*, 3951. (e) Danishefsky, S. J.; Larson, E.; Springer, J. P. *J. Am. Chem. Soc.* **1985**, *107*, 1274. (f) Vedejs, E.; McClure, C. K. *J. Am. Chem. Soc.* **1986**, *108*, 1094. Nitrile oxide cycloadditions: (g) Kozikowski, A. P.; Ghosh, A. K. *J. Org. Chem.* **1984**, *49*, 4674. (h) Jäger, V.; Schohe, R.; Paulus, E. F. *Tetrahedron Lett.* **1983**, *24*, 5501. (i) Houk, K. N.; Moses, S. R.; Wu, Y.-D.; Rondan, N. G.; Jäger, V.; Schohe, R.; Fronczek, F. R. *J. Am. Chem. Soc.* **1984**, *106*, 3880. (j) Curran, D. P.; Kim, B. H. *Synthesis*, in press. Hydroborations: (k) Schmid, G.; Fukuyama, T.; Akasaka, K.; Kishi, Y. *J. Am. Chem. Soc.* **1979**, *101*, 259. (l) Still, W. C.; Barrish, J. C. *J. Am. Chem. Soc.* **1983**, *105*, 2847. (m) Midland, M. M.; Kwon, Y. C. *J. Am. Chem. Soc.* **1983**, *105*, 3725. (n) Houk, K. N.; Rondan, N. G.; Wu, Y.-D.; Metz, J. T.; Paddon-Row, M. N. *Tetrahedron* **1984**, *40*, 2257. Halogenations: (o) Midland, M. M.; Halterman, K. L. *J. Org. Chem.* **1981**, *46*, 1227. (p) Chamberlin, A. K.; Dezube, M.; Dussault, P.; McMills, M. C. *J. Am. Chem. Soc.* **1983**, *105*, 5819. Electrophilic attack on allylsilanes: (q) Fleming, I.; Terrett, N. K. *J. Organomet. Chem.* **1984**, *264*, 99. (r) Chow, H.-F.; Fleming, I. *Tetrahedron Lett.* **1985**, *26*, 397. Protonation of enols: (s) Zimmerman, H. E.; Chang, W.-H. *J. Am. Chem. Soc.* **1959**, *81*, 3634. (t) Zimmerman, H. E.; Linder, L. W. *J. Org. Chem.* **1985**, *50*, 1637. Diels–Alder cycloadditions: (u) Gree, R.; Jilali, K.; Mosset, P.; Martelli, J.; Carriē, R. *Tetrahedron Lett.* **1984**, *25*, 3697. (v) Franck, R. W.; Argade, S.; Subramanian, C. S.; Frechet, D. M. *Tetrahedron Lett.* **1985**, *26*, 3187.

(2) The positions of the five atoms involved in isoxazoline formation were fixed at ab initio transition-state distances (Brown, F. K.; Houk, K. N., in press). The normal bond angles of groups attached to ethylene carbons were set at transition-state values, but these angles were optimized. Both ethylenic carbons were assigned as sp^3 carbons. Force constants for bending of bonds to H or C attached to C_5 were set at 0.15 and 0.25, respectively. All other parameters are normal MM2 values.[3]

(3) Allinger, N. L. *J. Am. Chem. Soc.* **1977**, *99*, 8127. Burkert, U.; Allinger, N. L. *Molecular Mechanics*; American Chemical Society: Washington, DC, 1982.

(4) MM2 calculations[3] indicate that the preferred ground-state geometry is approximately shown in the drawing of **2**. Compounds **2d** and **2e** have second energy minima, with the C=C—C—Me dihedral angle equal to 37°, which are only 0.6 kcal/mol above the lowest energy conformation.

(5) Caramella, P.; Rondan, N. G.; Paddon-Row, M. N.; Houk, K. N. *J. Am. Chem. Soc.* **1981**, *103*, 2438. Houk, K. N.; Paddon-Row, M. N.; Rondan, N. G.; Wu, Y.-D.; Brown, F. K.; Spellmeyer, D. C.; Metz, J. T.; Li, Y.; Loncharich, R. *Science (Washington, D.C.)* **1986**, *231*, 1108.

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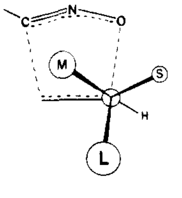
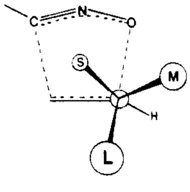
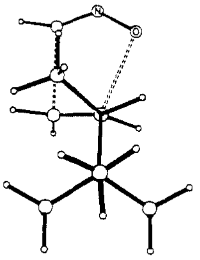


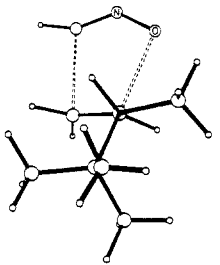
(A)



(B)



5



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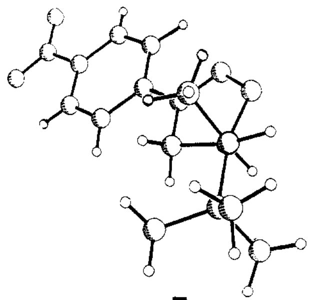

7

withdrawal from the electron-deficient transition state, but the preference for inside vs. outside probably occurs in order to minimize the repulsions between the allylic oxygen and the nitrile oxide oxygen. The reaction of 3-methoxy-3,4,4-trimethyl-1-pentene with PNBNO gives a 91:9 preference for the product with *t*-Bu anti, Me outside, and OMe inside. This also reflects the operation of the "inside alkoxy" effect. This effect causes an alkoxy group to be effectively larger than a methyl group, with respect to the oxygen of a nitrile oxide.

Model A is also appropriate for the major products of OsO_4 hydroxylations.[1c-f] The preferred product comes from A, with M = OH or OR and L = alkyl. We have also investigated the OsO_4 hydroxylation of alkene **2d**. Under standard conditions,[1c] two products are formed in a 90:10 ratio, the major product arising from A. Vedejs and McClure have discovered many examples which follow this model and show no indication of the operation of electronic effects.[1f,6]

Model A is the same as the Felkin–Anh version of Cram's rule for nucleophilic additions.[7] Other electrophilic reactions give the opposite stereochemical preference. Hydroborations with bulky alkylboranes or of *cis*-alkenes prefer model B, since the inside position is now more crowded than the outside. Reactions of electrophiles with chiral enolates also occur via B, most likely because these have very early transition structures, with geometries and conformations resembling those of reactants.[1t]

Structure **5** is the MM2 model for the transition state leading to the major product of reaction of **2e**. This is more stable than **6**, because the latter cannot simultaneously avoid methyl–O and *t*-Bu–CH_2 repulsions. Models **5** and **6** are very product-like with respect to the conformations about the bonds to the alkene. Indeed, X-ray crystal structures of products resemble the transition-state models to a remarkable degree. For example, **7** is the crystal structure of the major product of the reaction of **1** with **2e**. As in A, the largest alkyl group is anti, and the smaller alkyl group is inside. Thus, although the transition states are relatively early in terms of bond making and bond breaking, they are very product-like in terms of conformational preferences.[5]

Acknowledgment. We are grateful to the National Institutes of Health for financial support of this research and to Professor Edwin Vedejs for discussions and valuable suggestions.

Supplementary Material Available: X-ray data for **7**, including a stereo plot and tables of atomic coordinates, isotropic thermal parameters, bond distances and angles, and torsion angles (9 pages). Ordering information is given on any current masthead page.

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[6] Our MM2 model predicts that the alkoxy-anti, alkyl-outside conformation is preferred in the OsO_4 reactions of cis-disubstituted alkenes, as has been proposed by Vedejs.[1f]

[7] (a) Morrison, J. D.; Mosher, H. S. *Asymmetric Organic Reactions*; American Chemical Society: Washington, D.C., 1976. (b) Eliel, E. L. In *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: New York, 1983; Vol. 2, pp 125–156.

Oxygenation and [3 + 2] Cycloaddition of Methylenecyclopropanes through Electron Donor–Acceptor Complexes with Tetracyanoethylene by Photoexcitation and in the Dark[1]

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Received November 19, 1985

Recently, Kochi, Rentzepis, and co-workers spectroscopically demonstrated that the photoexcitation of electron donor–acceptor (EDA) complexes [DA] initially forms geminate radical ion pairs $[D^{+}\cdot A^{-}\cdot]$.[3a] Time-resolved spectroscopic studies by Kochi and co-workers further demonstrated that two processes, a rapid cage process to form adducts D–A and diffusion to solvent-separated radical cations $D^{+}\cdot$, competitively occur through $[D^{+}\cdot A^{-}\cdot]$.[3b]

$$[DA] \rightleftharpoons [D^{+}\cdot A^{-}\cdot]$$

$$[D\text{–}A] \leftarrow [D^{+}\cdot A^{-}\cdot] \rightleftharpoons D^{+}\cdot + A^{-}\cdot$$

Those intriguing spectroscopic observations prompted us to report our findings that oxygenation of methylenecyclopropanes (MCP) and the [3 + 2] cycloaddition of MCP with tetracyanoethylene (TCNE) through the EDA complexes with TCNE occurred not only by the photoexcitation but also in the dark. Herein we report clear-cut experimental observations that those two processes occurred independently through two different intermediates, significantly depending on the solvent polarity.

2,2-Diaryl-1-methylenecyclopropanes (**1a-c**) formed colored EDA complexes when mixed with TCNE in dry CH_2Cl_2.[4] When a colored solution of **1a** with TCNE in oxygen-saturated CH_2Cl_2 was irradiated (>390 nm) for 1 h at 20 °C, dioxolanes **2a**[5a] and **3a**[5a] were obtained together with cycloadducts **4a**[6] and **5a**.[6]

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[1] Organic Photochemistry. 75. Part 74: Kawamura, Y.; Kumagai, T.; Mukai, T. *Chem. Lett.* **1985**, 1937.

[2] Foster, R. *Organic Charge-Transfer Complexes*; Academic Press: London and New York, 1969; p 303. References were cited therein.

[3] (a) Hillinski, E. F.; Masnovi, J. M.; Amatore, C.; Kochi, J. K.; Rentzepis, P. M. *J. Am. Chem. Soc.* **1983**, *105*, 6167. Hilinski, E. F.; Masnovi, J. M.; Kochi, J. K.; Rentzepis, P. M. *J. Am. Chem. Soc.* **1984**, *106*, 8071. (b) Masnovi, J. M.; Levine, A.; Kochi, J. K. *J. Am. Chem. Soc.* **1985**, *107*, 4356.

[4] Charge-transfer absorption maxima of EDA complexes of **1** with TCNE in CH_2Cl_2 were 370 and 568 nm for **1a**, 388 and 540 nm for **1b**, 366 and 490 mm for **1c**, and 398 nm for **1d**.

[5] (a) Takahashi, Y.; Miyashi, T.; Mukai, T. *J. Am. Chem. Soc.* **1983**, *105*, 6511. (b) Miyashi, T.; Takahashi, Y.; Mukai, T.; Roth, H. D.; Schilling, M. L. M. *J. Am. Chem. Soc.* **1985**, *107*, 4356.

0002-7863/86/1508-2755$01.50/0