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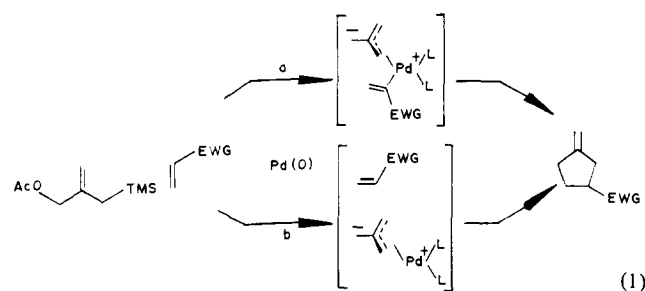
Donor Stereospecificity of Pd-Mediated Cycloadditions. A Case of Distal Attack of Acceptor on Donor

Barry M. Trost* and Thomas N. Nanninga

McElvain Laboratories of Organic Chemistry
Department of Chemistry, University of Wisconsin
Madison, Wisconsin 53706

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Transition-metal-mediated reactions are frequently viewed as associations of ligands on the surface of the metal. Excellent examples are carbonylations, reductions, and the oligomerization of olefins.¹ The cooligomerization of a methylenecyclopropane with a simple olefin may also involve just such a process.² When the Pd-mediated cycloaddition of 2-[(trimethylsilyl)methyl]allyl acetate (donor) with electron-deficient olefins (acceptors)³ is considered, an analogous process can be envisioned (eq 1, path a). The result of this prior coordination of the acceptor to the



metal would be to deliver the acceptor olefin to the same face of the trimethylenemethane-palladium complex (TMM-Pd) as the metal (proximal attack). In spite of the precedent that suggests the likelihood of this pathway, an alternative in which the acceptor reacts directly with the carbanion center on the face of the TMM-Pd complex away from the metal (distal attack) should be considered (eq 1, path b).

Differentiation of these pathways requires determining the stereochemistry of bonding to the TMM fragment. Thus, a substituted TMM unit with a stereochemical marker is required. Our initial attempts were thwarted when the acetate **3a**, easily available from *cis*-carveol⁴ by the direct metalation approach (eq 2),^{3a,5} failed to react with Pd(0) catalysts.⁶ Ancillary studies in

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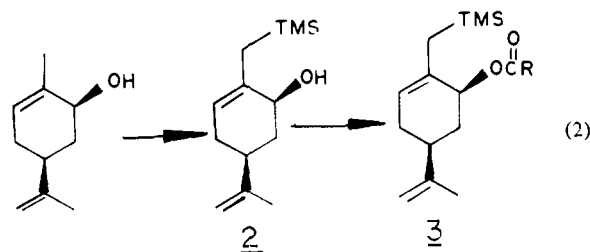
(2) Binger, P.; Cetinkaya, M.; Doyle, M. J.; Germer, A.; Schuchardt, U. *Fundam. Res. Homogeneous Catal.* **1979**, *3*, 271. Binger, P.; Schuchardt, U. *Chem. Ber.* **1980**, *113*, 3334; **1981**, *114*, 3313. Binger, P.; Bentz, P. J. *Organomet. Chem.* **1981**, *221*, C33. Binger, P.; Brinkmann, A.; Richter, W. J. *Tetrahedron Lett.* **1983**, *24*, 3599.

(3) (a) Trost, B. M.; Chan, D. M. T. *J. Am. Chem. Soc.* **1983**, *105*, 2315, 2326. (b) Trost, B. M.; Nanninga, T. N.; Chan, D. M. T. *Organometallics* **1982**, *1*, 1543. (c) Trost, B. M.; Chan, D. M. T. *J. Am. Chem. Soc.* **1981**, *103*, 5972. (d) Gordon, D. J.; Fenske, R. F.; Nanninga, T. N.; Trost, B. M. *J. Am. Chem. Soc.* **1981**, *103*, 5974.

(4) Ozawa, S.; Itoh, A.; Oshimo, K.; Nozaki, H. *Tetrahedron Lett.* **1979**, 2909.

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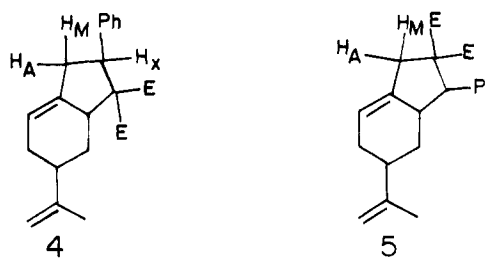
(6) Chan, D. M. T. Ph.D. Thesis, University of Wisconsin, Madison, 1982.



a) R = CH₃

b) R = OCH₃

the parent cyclohexenyl system suggested the greater reactivity of the carbonate may be beneficial. Indeed, reaction of **3b** with dimethyl benzylidenemalonate using 5 mol % of a Pd(0) catalyst generated in situ [1 equiv of Pd(OAc)₂, 2 equiv of *n*-C₄H₉Li, 5 equiv of Ph₃P] in refluxing THF gives an 86% yield of two products in a 4:1 ratio.⁸ The first question relates to regiochemistry (i.e., **4** or **5**). Both products show the presence of a

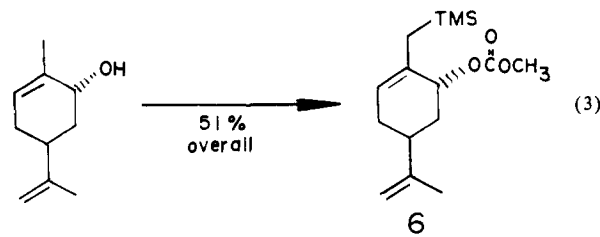


clean AM pattern for an isolated methylene group [major, δ 3.60 and 2.95, $J = 19.1$ Hz; minor, δ 3.45 and 2.66, $J = 16.9$ Hz], which is consistent only with **5**.

The critical question is stereochemistry. Four diastereomers (ignoring optical isomers) are possible (**5a-d**; see Chart I). Both isomers show a characteristic upfield absorption for 1 H as a quartet (major, δ 0.83, $J = 12.0$ Hz; minor, δ 1.05, $J = 12.0$ Hz), which has previously been shown to correspond to a *cis*-3,5-disubstituted cyclohexene—i.e., H_c in **5a** and **5b** in which $J_{bc} = J_{cd} = J_{ce}$.⁹ Double irradiation confirms this assignment. Furthermore, in the major isomer, the NMR spectrum taken in C₆D₆ reveals H_d at δ 1.62 as a ddd, $J = 12.0$, 5.0, and 2.3 Hz, in addition to H_c at δ 0.98 as a quartet, $J = 12.0$ Hz.

The benzylic proton appears as a doublet in both cases (major, δ 4.02, $J = 7.4$ Hz; minor, δ 3.52, $J = 12.8$ Hz)—a fact that reinforces the earlier conclusion regarding regioselectivity. Models reveal that the dihedral angle between H_a and H_b in **5a** is approximately 20°; whereas, it is approximately 180° in **5b**. Thus, the major isomer with the smaller J_{ab} is assigned as *cis*, *cis*.

To verify the stereospecificity, the epimeric carbonate **6** was prepared from *trans*-carveol¹⁰ in identical fashion with the *cis* series (see eq 3).¹¹ Cycloaddition as above produces a 7:3 ratio of two



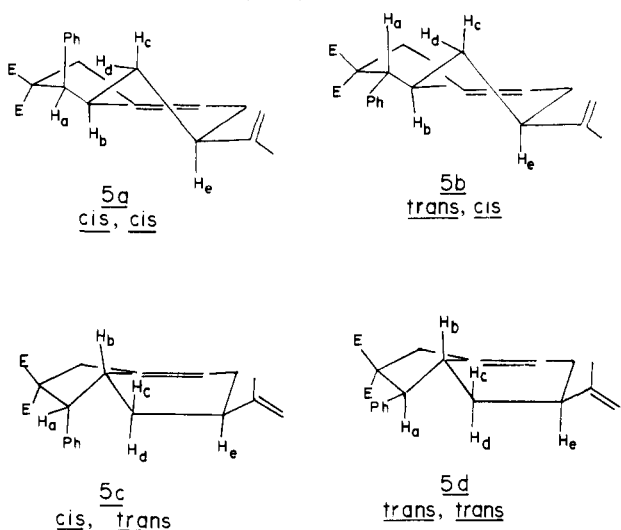
(7) All new compounds have been fully characterized spectrally and elemental composition determined by high-resolution mass spectroscopy. Unless otherwise noted, NMR spectra were taken in CDCl₃.

(8) A trace amount of a third product could be detected in the NMR spectrum. It is not the alternative stereoisomers **5c** nor **5d** by comparison to authentic samples. Unfortunately, it was present in such low amounts it could not be obtained pure. From the NMR spectral data of mixtures, it is tentatively assigned as the alternate regioisomer.

(9) Trost, B. M.; Verhoeven, T. R. *J. Am. Chem. Soc.* **1980**, *102*, 4730.

(10) Johnston, R. G.; Read, J. *J. Chem. Soc.* **1934**, 233.

Chart I. Diastereomeric Adducts



products⁷—neither of which corresponds to those obtained from **3**.¹² Again, the regioselectivity is established as corresponding to **5** not **4** by the presence of an isolated AM pattern for a CH₂ unit (major, δ 3.58 and 2.90, $J = 18.9$ Hz; minor, δ 3.42 and 2.63, $J = 16.2$ Hz) as well as a doublet for the benzylic proton (major, δ 3.99, $J = 7.5$ Hz; minor, δ 3.60, $J = 12.8$ Hz). The presence of an upfield proton as a ddd in both cases (major, δ 1.01, $J = 13.5, 9.8, 4.2$ Hz; minor, δ 1.24, $J = 13.4, 9.0, 4.0$ Hz) corresponds to the axial proton at C(4) in a trans-3,5-disubstituted cyclohexene⁹—i.e., H_c in **5c** and **5d**. In addition, the minor isomer reveals H_d also as a ddd at δ 1.82, $J = 13.4, 5.7, 5.3$ Hz. Double irradiation confirms these assignments. The stereochemistry of the phenyl group derives from models which suggests an approximately 20° dihedral angle for the cis,trans isomer but a nearly 180° dihedral angle for the trans,trans isomer. The smaller J_{ab} is associated with the smaller dihedral angle—a fact that suggests the major isomer is cis,trans-**5c**.

The chemo-, regio-, and diastereoselectivity of these reactions are remarkable. From a mechanistic point of view, they demonstrate that the new C–C bond is formed with net retention of stereochemistry with respect to the face of the allyl unit. Since the initial Pd-assisted ionization occurs with inversion of configuration,^{9,13} the new C–C bond also results from an inversion process—i.e., the distal approach as in eq 1, path b. To our knowledge, this example represents the first demonstration of a metal-catalyzed olefin addition not involving prior coordination of the olefin to the metal. A secondary stereochemical benefit is the selectivity for the phenyl group to become endo which can be interpreted to arise from an extended approach of the acceptor in which steric interactions are minimized.¹⁴ As expected,^{9,15} even though the starting materials are optically active, the products are racemic—a result of the symmetry expected from the initial ionization of the carbonate by palladium (i.e., **7**) as well as the likelihood that the TMM–Pd equilibrates (i.e., **8** = **9**).^{3a} The complexity of the TMM unit employed here bodes well for the generality of this cycloaddition approach to five-membered rings.¹⁶

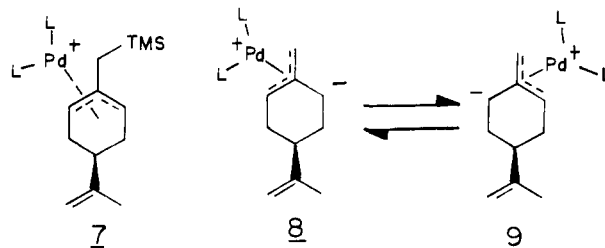
(11) An alcohol inversion of **2** using the Mitsunobu procedure which proceeds in 90% yield at 40% conversion also provides **6** after exchange of the initially formed benzoate to the carbonate. The benzoate also serves as a donor in the cycloaddition but in somewhat lower yields.

(12) Here, too, a trace amount of a third product that does not correspond to **5a** nor **5b** can be detected in the NMR spectrum. It is tentatively assigned as the alternative regioisomer but was present in insufficient amounts to isolate.

(13) Trost, B. M.; Verhoeven, T. R. *J. Am. Chem. Soc.* **1976**, *98*, 630; *J. Org. Chem.* **1976**, *41*, 3215. Hayashi, T.; Hagihara, T.; Konishi, M.; Kumada, M. *J. Am. Chem. Soc.* **1983**, *105*, 7767.

(14) This point will be discussed in more detail in future publications.

(15) Trost, B. M.; Schmuff, N. R. *Tetrahedron Lett.* **1981**, *22*, 2999. However, also see: Fiaud, J. C.; Malleron, J. L. *Tetrahedron Lett.* **1981**, *22*, 1399.



It does illustrate the importance of the choice of the leaving group for successful reactions.¹⁷

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Registry No. **2**, 94348-83-1; **3b**, 94348-84-2; (\pm)-**5** (isomer 1), 94369-80-9; (\pm)-**5** (isomer 2), 94348-85-3; (\pm)-**5** (isomer 3), 94348-86-4; (\pm)-**5** (isomer 4), 94348-87-5; **6**, 94348-88-6; Pd(OAc)₂, 33571-36-7; BuLi, 109-72-8; Ph₃P, 603-35-0; *cis*-carveol, 1197-06-4; *trans*-carveol, 1197-07-5; dimethyl benzylidenemalonate, 6626-84-2.

(16) The most complex TMM units previously employed involved intramolecular cycloadditions. See: Trost, B. M.; Chan, D. M. T. *J. Am. Chem. Soc.* **1982**, *104*, 3733.

(17) For the first case of an allyl carbonate, see: Trost, B. M.; Masse, G., unpublished work, quoted in the following. Trost, B. M.; Runge, T. A. *J. Am. Chem. Soc.* **1981**, *103*, 7550. For extensive studies of this leaving group, see: Trost, B. M.; Hung, M.-H. *J. Am. Chem. Soc.* **1983**, *105*, 7757. Tsuji, J.; Shimizu, I.; Minami, I.; Ohashi, Y. *Tetrahedron Lett.* **1982**, *23*, 4809.

Competing Pathways in the Photolysis of Bicyclo[1.1.0]butane

Alan F. Becknell,[†] Jerome A. Berson,^{*†} and R. Srinivasan^{*†}

Department of Chemistry, Yale University
New Haven, Connecticut 06511
IBM Thomas J. Watson Research Center
Yorktown Heights, New York 10598

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The vacuum ultraviolet (VUV) photochemistry of simple cyclopropane derivatives in the gas phase¹⁻³ and in solution^{4,5} is dominated by a two-bond scission to give an olefin and a carbene. In the gas phase at 167 and 147 nm, the methylene-extrusion channel is stereospecific for retention: *cis*- and *trans*-1,2-dimethyl cyclopropane give *cis*- and *trans*-2-butene, respectively.³ This result supports a concerted mechanism. In the solution-phase photolysis at 185 nm, the results are less easily interpreted, but a sequential rather than a concerted cleavage of the two bonds seems likely.⁵

Applied to bicyclo[1.1.0]butane (**1**), the latter mechanism might offer a hydrocarbon route to cyclobutane-1,3-diyl (**2**), a biradical⁶

[†]Yale University.

^{*}IBM Thomas J. Watson Research Center.

(1) Currie, C. L.; Okabe, H.; McNesby, J. R. *J. Phys. Chem.* **1963**, *67*, 1494.

(2) (a) Lopez, E.; Doepker, R. D. *J. Phys. Chem.* **1979**, *83*, 573. (b) Lopez, E.; Doepker, R. D. *Ibid.* **1978**, *82*, 753. (c) Dhingra, A. K.; Vorachek, J. H.; Koob, R. D. *Chem. Phys. Lett.* **1971**, *9*, 17. (d) Scala, A. A.; Ausloos, P. J. *J. Chem. Phys.* **1968**, *49*, 2282.

(3) (a) Dhingra, A. K.; Koob, R. D. *J. Phys. Chem.* **1970**, *74*, 4490. (b) Dees, K.; Koob, R. D. *Ibid.* **1973**, *77*, 759. (c) Pendleton, T. S.; Kaplan, M.; Doepker, R. D. *Ibid.* **1980**, *84*, 472.

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