Tetrahedron Letters,Vol.30,No.14,pp 1769-1772,1989 0040-4039/89 $3.00 + .00
Printed in Great Britain Pergamon Press plc

Controlling Stereochemistry in Crotyl Additions To Aldehydes with Crotylmolybdenum Complexes

J.W. Faller , J.A. John and M.R. Mazzieri

Department of Chemistry, Yale University, New Haven, CT 06511

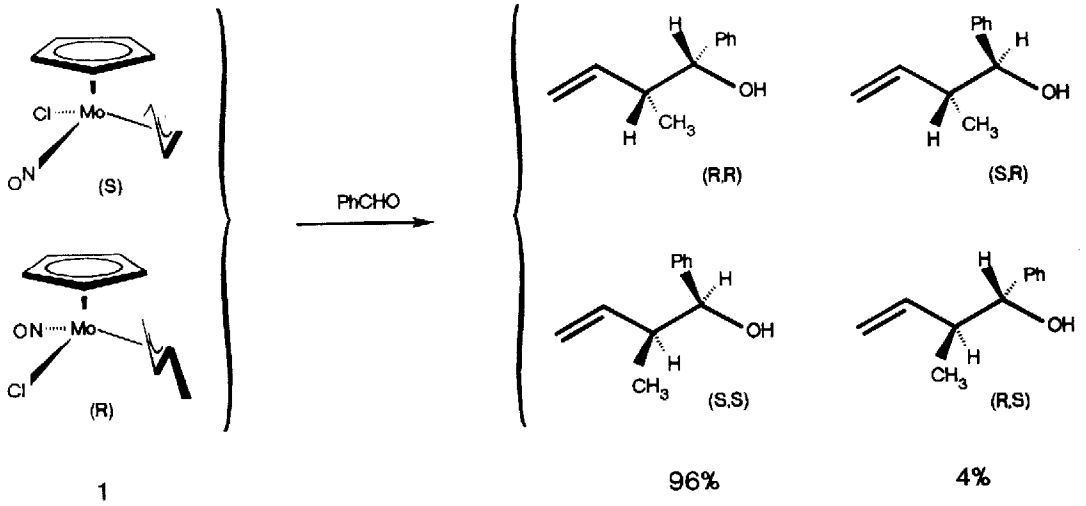
Summary. Air stable (Cyclopentadienyl)Mo(NO)(Cl)(π-crotyl) complexes add to aldehydes in the presence of methanol to yield homoallylic alcohols with high regioselectivity and diastereoselectivity. Reaction of (-)-(S)-(Neomenthylcyclopentadienyl)Mo(NO)(Cl)(π-crotyl) with benzaldehyde yields (+)-(R,R)-2-methyl-1-phenyl-3-buten-1-ol in >98% ee.

The enantioselective synthesis of secondary homoallylic alcohols is of considerable interest in the context of acyclic stereoselective synthesis.[1] Control of stereochemistry at the β-carbon and in consecutive stereogenic centers is essential in syntheses of precursors to natural products such polyketides.[2] The condensation of carbonyl compounds with main group allyl reagents has been shown to be a successful strategy in this respect.[2-7] In particular, asymmetric induction through the use of chiral metal templates has been developed. B-allyl boranes have been extensively studied owing to the relative ease of incorporation of chiral moieties. These chiral B-allylboranes have been derived from camphor glycols[4,5] and most recently from α-pinene[6] and diisopropyl tartrate.[7] These B-allyl reagents were shown to smoothly add to the aldehydes transferring the allyl group to the carbonyl carbon in 55-96% ee.

Our preliminary studies[8] of homoallyl alcohol synthesis via condensation of aldehydes with CpMo(NO)(Cl)(η^3-C_3H_4-2-Me) complexes demonstrated that the reaction occurs in high yield. Furthermore, this suggests that high enantioselectivity could be anticipated using homochiral complexes. In an effort to bring the potential of these molybdenum reagents to the attention of the synthetic community, we report here our studies of distereoselectivity in reactions of aldehydes with the CpMo(NO)(Cl)(η^3-crotyl), **1**, complex.

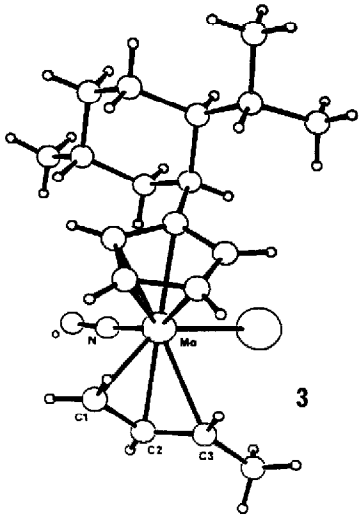
Treatment of benzaldehyde with **1** in methanol/CH_2Cl_2 (ratio PhCHO:**1** = 2:1) yields a (RR,SS):(RS,SR) ratio of products of 22:1 demonstrating an effective mutual kinetic resolution.

Under these conditions the reaction is relatively slow (48 hrs). With excess aldehyde the reaction is faster, but the selectivity decreases.



1 96% 4%

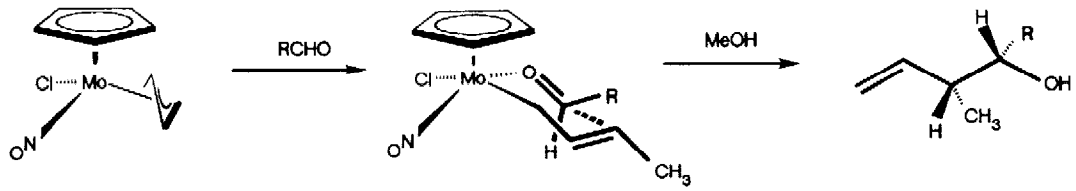
One obtains $[CpMo(NO)(CO)(\pi\text{-crotyl})]BF_4$ by treating the $CpMo(CO)_2(\pi\text{-crotyl})$ with $NO^+BF_4^-$. Considering that four geometric isomers are possible for the product, it is impressive that addition of NO^+ to the dicarbonyl complex yields only a single isomer. Addition of LiCl in acetone gives the chloride as an air stable complex, 1. Use of the neomenthylcyclopentadienyl analog of 1 provides a straightforward resolution of the chiral metal center[9,10] and a route to nonracemic chiral condensation products. The absolute configuration at the metal is (S) for (-)-NMCpMo(NO)(Cl)(π-crotyl), (-)-2, as shown by correlation with that of (S)-NMCpMo(NO)(I)(π-crotyl), 3, for which a single crystal x-ray structure determination has been carried out.[11-14] Hence, (-)-2 has the same stereochemistry as that shown here for iodide 3.



3

Compound (-)-2 reacts with benzaldehyde in the presence of methanol to yield the (R,R)-2-methyl-1-phenyl-3-buten-1-ol in >98% ee and 92% de. This compares favorably to the crotylboronate based on diisopropyl tartrate which yields 67% ee.[7e] The origin of this extraordinary selectivity with this molybdenum reagent lies in the electronic asymmetry created by the differential

backbonding capabilities of the nitrosyl and halide ligands. The ground state structure of 3 shows the effect of this asymmetry on the bonding within the η^3-crotyl group. For the iodide, 3, the allyl carbon cis to nitrosyl, *C1*, is 2.243(6) Å, whereas that trans to nitrosyl, *C3* is lengthened by more than 0.3 Å to 2.574(7) Å. The η^3-crotyl is also distorted to a σ-π-type of bonding, as indicated by the *C1-C2* distance of 1.42(1) Å compared to the *C2-C3* distance of 1.26(1) Å. This is reflected in a relatively low barrier of ~18 kcal/mol for η^3-η^1-η^3 interconversion, which can be detected by NMR.[15] As anticipated by the distortion toward a π-σ-crotyl in the solid state structure, the σ-bond forms at the terminus *cis* to the nitrosyl, which opens the latent coordination site for the aldehyde trans to the nitrosyl. Considering a transoid preference for a σ-bonded aldehyde, a chairlike transition state is generated which provides for the ultimate control of the diastereoselectivity. The preferred orientation of the aldehyde demanded by decreased interaction with the Cp ring, thus exposes the *re* face of the aldehyde to attack and accounts for the high enantiofacial selectivity.[16,17]



We are currently testing the generality of these reactions; preliminary evidence with racemic systems suggests that this approach will be effective for both aliphatic, unsaturated and aromatic aldehydes.[18] The degree of reagent control of stereoselectivity would appear to be high and we are currently investigating reactions with homochiral aldehydes. Furthermore, we are examining other alternatives to neomenthyl substitution for resolution of the metal center. The relative ease of synthesis and remarkable insensitivity to air, moisture, and alcohols suggest that crotylmolybdenum complexes such as these should by highly effective in the synthesis of homoallylic alcohols.

Acknowledgement. We wish to thank the National Science Foundation for support, the Consejo Nacional de Investigaciones Cientificas y Téchnicos of Argentina for a fellowship to MRM, D.L. Linebarrier for helpful discussions, and William Roush for providing complete physical data to allow determination of our product absolute configurations, as well as a preprint of his new work.

1. Poulter, C.D.; Rilling, H.C. *Acc. Chem. Res.* **1978**, 11, 307.
2. (a) S. Masamune, W. Choy, J.S. Petersen, L.R. Sita, *Angew. Chem. intl. Ed. Engl.*, **1985**, 24, 1. (b) R.W. Hoffmann, *Ibid.*, **1987**, 26, 489. (c) C.H. Heathcock, in *Asymmetric Synthesis*, v 3, 111, Morrison, ed., **1984**, Academic Press
3. (a) Jephcote, V.J.; Pratt, A.J.; Thomas, E.J. *J. Chem. Soc., Chem. Commun.* **1984**, 800. (b) Otera, J.; Yoshinaga, Y.; Takeshi, Y.; Takakazu, Y.; Kawasaki, Y. *Organometallics* **1985**, 4, 1213.
4. Mukaiyama, T.; Minowa, N; Oriyama, T.; Narasaka, K. *Chem. Lett.* **1986**, 97
5. (a) Hoffmann, R.W.; Herold. T. *Angew. Chem., Int. Ed. Engl.* **1978**, 17, 768. (b) Hoffmann, R.W.; Herold, T.; Schrott, U. *Chem. Ber.* **1981**, 114, 359. (c) Hoffmann, R.W.; Herold, T. *Ibid.* **1981**, 114, 375. (d) Hoffmann, R.W.; Zeiß, H.-J., *J. Org. Chem.*, **1981**, 46, 1309.
6. (a) Brown, H.C.; Jadhav, P.K. *J. Am. Chem. Soc.* **1983**, 105, 2092. (b) Brown, H.C.; Jadhav, P.K.; Bhat, K.S.; Perumal, P.T. *J. Org. Chem.* **1986**, 51, 432. (c) Brown, H.C.; Bhat, K.S. *J. Am. Chem. Soc.* **1986**, 108, 293. (d) Brown, H.C.; Krishna, S.B.; Randad, R.S. *J. Org. Chem.* **1987**, 52, 320.
7. (a) Roush, W.R.; Walts, A.E.; Hoong, L.K. *J. Am. Chem. Soc.* **1985**, 107, 8186. (b) Roush, W.R.; Halterman, R.L. *Ibid.* **1986**, 108, 294. (c) Roush, W.R.; Adam, M.A.; Walts, A. E.; Harris, D.J. *Ibid.* **1986**, 108, 3422. (d) Roush, W.R.; Palkowitz, A.D.; Palmer, M.A.J. J. Org. Chem. **1987**, 52, 316. (e) W.T. Roush, K. Ando, D.B. Powers, R.L. Halterman, and A.D. Palkowitz, *Tetrahedron Lett.*, **1988**, 29, 5579. (f) *Idem*, *J. Am. Chem. Soc.*, submitted.
8. Faller, J.W.; D.L. Linebarrier, *J. Am. Chem. Soc.* **1989**, in press.
9. The preparations follow those given previously for the analogous Mo(allyl) complexes. [10]
10. Faller, J. W.; Shvo, Y.; Chao, K-H.; Murray, H. H. *J. Organomet. Chem.* **1982**, 226, 251.
11. Absolute configurations for stereogenic centers in metals are based on priorities for 2 of Cp>crotyl>Cl>NO; whereas for 3 the priorities are I>Cp>crotyl>NO.[12] Thus, (S)-2 has the same sense of chirality and the same spatial arrangement of CpMo(NO)(X)(crotyl) as (S)-3.
12. T.E. Sloan, *Topics in Stereochem.*, **1981**, 12, 1.
13. Crystals suitable for x-ray diffraction could only be grown for the iodide, (+)-(S)-3. Halide substitution has been previously shown to occur with retention.[10]
14. The absolute configuration of the metal in (+)-3 was determined to be (S) by x-ray crystallography using the known configurations within the neomenthyl group. This complex crystallizes in the orthorhombic space group $P2_12_12_1$ (#19) with a = 7.611(1); b = 12.370(3), c = 21.958(3), V = 2067.4(6) Å^3, R = 0.026. The methods have been discussed previously.[10]
15. The crystal structure shows the crotyl in the *endo-trans* conformation. The *exo-trans* conformer is formed via $\pi \rightarrow \sigma \rightarrow \pi$ rearrangement. The resonances for both conformer are observed in the NMR shortly after dissolving.
16. (-)-(S)-NMCpMo(NO)(Cl)(π-2-methylallyl) (>98% de) adds to the *re* face of PhCHO yielding (+)-(R)-3-methyl-1-phenyl-3-buten-1-ol in 98%ee and 60% isolated yield. The absolute configuration of this product has been determined previously.[6b] Crotyl addition gives the *anti* diastereomer by comparison of NMR[5d], and configuration is (RR) by analogy with 2-methylallyl. The (-)-isomer has also been shown to be (RR) by Roush et al.[8d,8f]
17. The ee of the product alcohol was determined by addition of Eu(tfc)$_3$ to a benzene-d_6 solution of the nonracemic alcohol. Upon shifting of the methyl doublet greater than δ1.00 the enantiomers are cleanly resolved. No trace of the other enantiomer could be observed when using homochiral (-)-(2), $[\alpha]_D^{25}$ = -86°. Addition of 11% racemic alcohol gave one doublet at δ1.00 and another at δ0.98 in a ratio of 95:5.
18. In a typical preparation, 212 mg (2 mmol) PhCHO was added to one equivalent of (-)-2 (281 mg) in CH_2Cl_2 containing 96 mg (3 mmol) MeOH. The solution, which was initially yellow, was stirred for 72 H at room temperature. The molybdenum containing products were removed by filtration through alumina and elution of the product with CH_2Cl_2. The yield was 92% based on NMR integration of crude product. Column chromatography on alumina (hexane/ether) gave 96 mg (59%) (+)-*anti*-2-methyl-1-phenyl-3-buten-1-ol.

(Received in USA 3 January 1989)