STEREOSELECTIVE EPOXIDATION OF ACYCLIC ALLYLIC ALCOHOLS.
A CORRECTION OF OUR PREVIOUS WORK.[1]

B. E. Rossiter, T. R. Verhoeven,[16] and K. B. Sharpless*
Department of Chemistry, Stanford University
Stanford, California 94305

A reinvestigation of the stereoselectivities for the epoxidation of acyclic allylic alcohols with MCPBA, and with tert-butyl hydroperoxide catalyzed by V[+5] and Mo[+6] revealed a number of errors in our original work[1] which are rectified. Optimum O—C—C≡C dihedral angles are proposed.

Several years ago, in collaboration with the Yamamoto/Nozaki group, we reported on the stereoselective epoxidation of acyclic allylic alcohols with tert-butyl hydroperoxide (TBHP) catalyzed by vanadium (+5) and molybdenum (+6).[1] We have recently discovered errors in our portion of this work.[2] The errors involved both incorrect erythro/threo structural assignments of the epoxidation products as well as inaccurate determinations of the erythro/threo ratios. We had largely accepted the structural assignments of Pierre, et. al.,[3] one of which he has recently reversed.[4,5] However, most of the errors[6] in our previous work were due to our own mistakes. The corrections[6] to our original publication are presented in Table I, with the structures of all of the epoxy alcohols being verified by conversion to (and direct comparison with authentic samples of) known erythro and threo vicinal diols.[7] The erythro/threo ratios have been verified by two independent methods (NMR and GLC). Further substantiation of these results can be found in the accompaning manuscript[8] by Dr. E. D. Mihelich, who independently discovered errors in our earlier work.[1]

Analysis of the corrected results in Table I reveals a pattern of definite predictive value. The molybdenum, and especially the vanadium catalyzed epoxidations favor formation of erythro-epoxy alcohols. This tendency reaches a zenith with geminally disubstituted olefins 4 and 5. With olefins 7 and 8, which bear alkyl substituents cis to the hydroxyl bearing carbon, the trend reverses, and threo-epoxy alcohols predominate. In contrast, MCPBA exhibits a generally weak preference for the threo-isomer (except with olefins 7 and 8 where a strong preference is observed).

There has been considerable recent interest in assigning optimum O—C—C≡C dihedral angles for epoxidations of allylic alcohols with both peroxy acids[4,9] and vanadium catalysts.[10,11] The conclusions reached in earlier studies drew support from epoxidation results on conformationally restrained[13] tert-butylcyclohexenols, and suggested optimum dihedral angles of ∼150° (peracid epoxidations)[9,10,11] and ∼90° (V[5] catalyzed epoxidations).[10] These suggested values do not seem to agree very well with our results for acyclic allylic alcohols. A priori one would expect the stereoselectivities with these conformationally mobile acyclic substrates to more closely reflect the true preferred transition state geometries.[13] Therefore, we feel that in both the vanadium and the peracid epoxidations somewhat tighter O—C—C≡C

Table I. Stereochemistry of Epoxidation of Acyclic Allylic Alcohols.[a]

Olefin		Threo	Erythro
R = CH₃ **1**	V⁺⁵,TBHP[b,e]	20	80
	Mo⁺⁶,TBHP[c,e]	44	56
	MCPBA[d]	60	40
R = C₂H₅ **2**	V⁺⁵,TBHP	20	80
	Mo⁺⁶,TBHP	42	58
	MCPBA	61	39
R = i-C₃H₇ **3**	V⁺⁵,TBHP	15	85
	Mo⁺⁶,TBHP	35	65
	MCPBA	58	42
R = CH₃ **4**	V⁺⁵,TBHP	5	95
	Mo⁺⁶,TBHP	16	84
	MCPBA	45	55
R = n-C₄H₉ **5**	V⁺⁵,TBHP	2	98
	Mo⁺⁶,TBHP	16	84
	MCPBA	41	59

Olefin		Threo	Erythro
6	V⁺⁵,TBHP	29	71
	Mo⁺⁶,TBHP	62	38
	MCPBA	64	36
7	V⁺⁵,TBHP	71	29
	Mo⁺⁶,TBHP	84	16
	MCPBA	95	5
8	V⁺⁵,TBHP	86	14
	Mo⁺⁶,TBHP	95	5
	MCPBA	95	5

dihedral angles (vanadium ∿50°; peracid ∿120°[14]) are in better accord with the data. Our preferred conformations are illustrated in Scheme I for both the peracid (11 and 12) and vanadium catalyzed (9 and 10) epoxidations. In choosing the angles shown in Scheme I, emphasis was given to the results with allylic alcohols 4 and 5 (R_1 and R_2 = alkyl and 7 and 8 (R_1 and R_3 = alkyl). These two structural types exhibit the largest changes in selectivities over the parent allylic alcohols (i.e. 1, 2 and 3.

Scheme I.   Predicted O—C—C≡C Dihedral Angles:
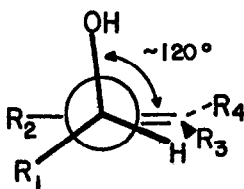
for V^{+5}, TBHP epoxidations:
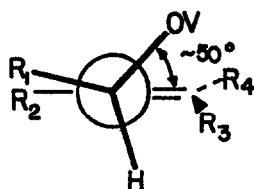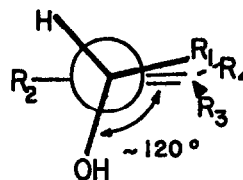

9, leads to threo product
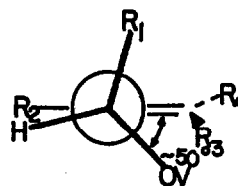
10, leads to erythro product

for peroxy acid (MCPBA) epoxidations:

11, leads to threo product

12, leads to erythro product

The mechanistic picture presented herein, though simplified by considering solely the interactions within the allyloxy moiety, provides a useful model for prediction of the stereoselectivity in epoxidations of acyclic allylic alcohols. A more detailed mechanistic discussion will appear shortly.[15]

Reference and Notes:

1.   S. Tanaka, H. Yamamoto, H. Nozaki, K. B. Sharpless, R. C. Michaelson, and J. D. Cutting J. Am. Chem. Soc., 96, 5254 (1974).

2.   We wish to emphasize that the errors are all due to our group and have no bearing on that portion of the publication contributed by our Japanese colleagues (i.e. the juvenile

hormone synthesis and trisubstituted olefin synthesis). For a full paper on those aspects of the original work see A. Yasuda, S. Tanaka, H. Yamamoto, and H. Nozaki Bull. Chem. Soc. Jap., 52, 1701 (1979).

3. J.-L. Pierre, and P. Chautemps and P. Arnaud, Bull. Soc. Chim. Fr., 1317 (1969).

4. P. Chautemps and J.-L. Pierre, Tetrahedron, 32, 549 (1976).

5. One of us (KBS) is grateful to S. A. Biller of the California Institute of Technology for bringing Pierre's structural revision[4] to our attention. This prompted our re-investigation, ultimately uncovering the errors described herein.

6. The crucial errors can be noted by comparing the results for allylic alcohols 1, 2, 3, 4, and 6 in Table I with the results cited in the earlier publication.[1]

7. The epoxy alcohol product mixtures from 1 were converted to mixtures of threo and erythro-2,3-dihydroxyoctanes by reaction with excess (5 equiv.) lithium di-n-butyl-cuprate and compared (NMR,GLC) to authentic samples prepared by osmylation of (E) and (Z)-2-octene respectively. The epoxy alcohols derived from 2, were converted to mixtures of threo-and erythro-3,4-dihydroxyhexanes by reaction with lithium dimethylcuprate and compared to authentic samples prepared from (E)-and (Z)-3-hexene. Threo and erythro-2,3-dihydroxy-4-methylpentanes (13) prepared from (E)-and (Z)-4-methyl-2-pentene respectively, served to correlate the epoxide mixtures derived from 3, 6, and 8. The epoxy alcohols from 3 were converted to 13 by reduction with lithium aluminum hydride. Lithium dimethylcuprate addition to the epoxides from 6 similarly produced diols 13. Treatment of the epoxides from 8 with LDA (ether, r.t.) gave 3,4-dihydroxy-2-methyl-1-pentene which upon hydrogenation (PtO$_2$) provided 13 for comparison to authentic samples. Copper (I) catalyzed addition of ethylmagnesium bromide to the epoxy alcohols from 4 produced threo-and erythro-2,3-dihydroxy-3-methylhexanes compared to authentic samples prepared from (E)-and (Z)-3-methyl-2-hexene. Lithium aluminum hydride reduction of the epoxides from 7 produced threo-and erythro-2,3-dihydroxypentanes compared to authentic samples prepared from (E)-and (Z)-2-pentenes.

8. E. D. Mihelich, Tetrahedron Lett., preceding paper in this issue.

9. P. Chamberlain, M. L. Roberts, and G. H. Whitham, J. Chem. Soc. (B), 1374 (1970).

10. T. Itoh, K. Jitsukawa, K. Kaneda, and S. Teranishi, J. Am. Chem. Soc., 101, 159 (1979).

11. R. B. Dehnel and G. H. Whitham, J. Chem. Soc., Perkin I, 953 (1979).

12. Chautemps and Pierre proposed two different optimum O—C—C≡C dihedral angles (ca. 0° and ca. 120°) from analysis of the results of their extensive studies on the peracid epoxidations of acyclic allylic alcohols.[4]

13. The highly different steric environments between equatorial and axial positions in cyclohexenols as well as the rapid half-chair/half-boat interconversion could cloud interpretation of epoxidation results based on such models.

14. We had originally preferred a dihedral angle near 90° for these peracid epoxidations. We would like to thank Professor Satoru Masamune for pointing out to us that the data (Table I) appears to better fit a dihedral angle near 120°. Pierre had earlier proposed 120° as a possible preferred dihedral angle.[4,12]

15. K. B. Sharpless, Aldrichimica Acta, 12, issue 4 (1979).

16. National Institutes of Health Postdoctoral Fellow, 1979-1981.