give an oily residue, which was purified by preparative high-performance chromatography (Waters Preparative Liquid Chromatographic System 500A), using 15% ethyl acetate–85% petroleum ether (60–70 °C) and a silica gel column. This gave 0.55 g (47%) of **6**, which was distilled to give 0.45 g (39%) of analytically pure material: bp 78–79 °C (0.35 mm); ^{1}H NMR ($CDCl_3$) δ 1.52 (6 H, s), 2.20 (1 H, br s), 5.31 (2 H, d, J_{HF} = 48.0 Hz), 7.10–7.60 (4 H, br m); ^{13}C NMR ($CDCl_3$) δ 149.53 (s), 135.90 (d, J_{CCF} = 16.9 Hz), 128.33 (d), 125.68 (d of d, J_{CCCF} = 5.7 Hz), 124.74 (d of d, J_{CCCCF} = 3.11 Hz), 123.48 (d of d, J_{CCCF} = 5.9 Hz), 84.61 (d of t, J_{CF} = 166.0 Hz), 72.26 (s), 31.55 (q); exact mass calcd for $C_{10}H_{13}FO$ 168.0950, found 168.0951.[11]

2-[3-(Fluoromethyl)phenyl]-2-propyl Chloride (7). A solution of 0.32 g of **6** in 2 mL of dry methylene chloride was cooled to 0 °C and dry hydrogen chloride gas was bubbled into the solution for 1.75 h. The solvent was removed under reduced pressure to give 0.31 g (88%) of **7**, which contained no alcohol or substituted propene on analysis by ^{1}H NMR. All attempts at additional purification resulted in decomposition (loss of hydrogen chloride). Thus, the material was used without additional purification: ^{1}H NMR ($CDCl_3$) δ 1.99 (6 H, s), 5.38 (2 H, d, J_{HF} = 47.7 Hz), 7.29–7.60 (4 H, m); exact mass calcd for $C_{10}H_{12}ClF$ 186.0610, found 186.0605.[11]

Kinetic Procedure. The kinetic procedure was essentially that of Brown and Okamoto except that the rates were measured conductometrically. Excellent psuedo-first-order kinetics were observed for at least 5 half-lives.

Acknowledgment. We are indebted to the National Science Foundation for Grants CHE78-10231 and CHE81-14772, which supported this investigation.

Registry No. **1**, 3132-99-8; **2**, 15852-73-0; **3**, 82732-02-3; **4**, 456-43-9; **5**, 82732-03-4; **6**, 82732-04-5; **7**, 82732-05-6; *m*-lithiobenzyl fluoride, 82732-06-7; acetone, 67-64-1.

(11) Due to the tendency of this compound to slowly decompose, an elemental analysis was omitted.

Communications

High Asymmetric Induction in the 1,3-Dipolar Cycloaddition of (*R*)-(+)-*p*-Tolyl Vinyl Sulfoxide with Acyclic Nitrones

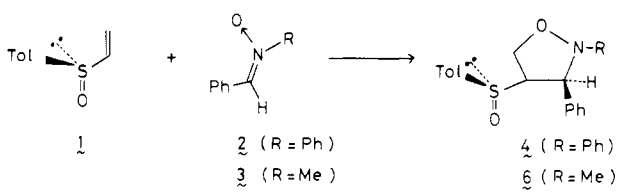
Summary: High chiral induction was observed in the 1,3-dipolar cycloaddition of (*R*)-(+)-*p*-tolyl vinyl sulfoxide with two typical acyclic nitrones.

Sir: In contrast to the well-documented asymmetric Diels–Alder reactions,[1] asymmetric 1,3-dipolar cycloadditions have been little explored. Recently, Uskokovic[2] and Belzecki[3] observed asymmetric inductions in the cycloaddition of chiral nitrones.[4] To our best knowledge, however, there have been no reports concerning asymmetric 1,3-dipolar cycloaddition using chiral dipolarophiles.

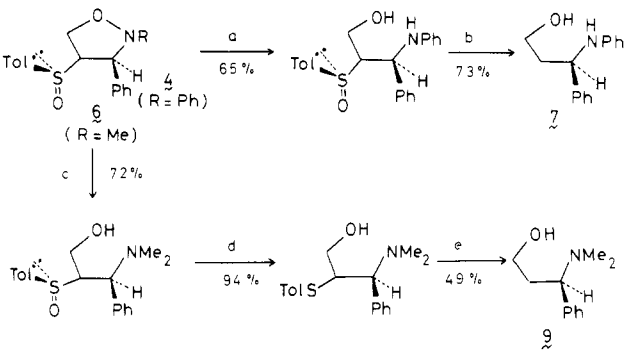
We here report that a chiral vinyl sulfoxide,[5] (*R*)-(+)-*p*-tolyl vinyl sulfoxide, exhibits high chiral induction in the 1,3-dipolar cycloaddition with typical nitrones.

A benzene solution of (*R*)-(+)-*p*-tolyl vinyl sulfoxide **1**[6] and 3 molar equiv excess of *C,N*-diphenylnitrone (**2**) was heated under reflux for 20 h, and the reaction product was separated by silica gel column chromatography to afford 3-phenyl-4-(*p*-tolylsulfinyl)isoxazolidines[7] **4a** and **4b**[8] in

Scheme I



Scheme II



[a] Raney Ni-H_2. [b] Raney Ni-EtOH, 60 °C. [c] (i) MeI; (ii) Zn-AcOH, room temperature. [d] $TiCl_3$-AcOH-AcONa, room temperature. [e] Raney Ni-EtOH, room temperature.

54% and 3% yields, respectively (Scheme I). Both **4a** and **4b** afforded the same sulfide **5**[9] after $LiAlH_4$ reduction,

(1) (a) J. D. Morrison and H. S. Mosher, "Asymmetric Organic Reactions", Prentice-Hall, Englewood Cliffs, NJ, 1971; (b) W. Oppolzer, M. Kurth, D. Reichlin, and F. Moffatt, *Tetrahedron Lett.*, **22**, 2545 (1981); (c) E. J. Corey and H. E. Ensley, *J. Am. Chem. Soc.*, **97**, 6908 (1975).

(2) P. M. Wovkulich and M. R. Uskokovic, *J. Am. Chem. Soc.*, **103**, 3956 (1981).

(3) C. Belzecki and I. Panfil, *J. Org. Chem.*, **44**, 1212 (1979).

(4) A. Vasella, *Helv. Chim. Acta*, **60**, 1273 (1977).

(5) Chiral vinyl sulfoxides have been extensively employed as Michael acceptors: (a) G. H. Posner, J. P. Mallamo, K. Miura, and M. Hulce, *Pure Appl. Chem.*, **53**, 2307 (1981), and references cited therein; (b) G.-I. Tsuchihashi, S. Mitamura, S. Inoue, and K. Ogura, *Tetrahedron Lett.*, 323 (1973).

(6) (a) (*R*)-(+)-*p*-Tolyl vinyl sulfoxide 1 [bp 110 °C (1.0 torr); $[\alpha]^{26}_D$ +421°(*c* 0.15, EtOH)] was prepared according to the method of D. J. Abbott, S. Colonna, and C. J. M. Stirling, *J. Chem. Soc., Perkin Trans. 1*, 492 (1976); (b) All numbered compounds had satisfactory mass and/or combustion analyses and IR and ^{1}H NMR spectral properties. All distillations were carried out by use of Kugelrohr apparatus, and the bath temperatures are described.

(7) Other isoxazolidines were not observed even by the careful examination of every chromatographic fraction. The 4-substituted isoxazolidine structure for **4** was assigned by ^{1}H NMR spectra and the subsequent transformations.

(8) Both **4a** and **4b** decomposed on the attempted microdistillation. **4a**: viscous oil; mass spectrum, *m/z* 363 (M^+); TLC (silica gel) R_f 0.52 (benzene–AcOEt 6:1); $[\alpha]^{24}_D$ +246°(*c* 0.63, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.39 (3 H, s), 3.81 (1 H, 7-line m, *J* = 7, 5, 3 Hz), 4.11 (1 H, dd, *J* = 10, 5 Hz), 4.18 (1 H, dd, *J* = 10, 7 Hz), 5.27 (1 H, d, *J* = 3 Hz), 6.96–7.60 (14 H). **4b**: viscous oil; mass spectrum, *m/z* 363 (M^+); TLC R_f 0.45 (benzene–AcOEt, 6:1); $[\alpha]^{24}_D$ −11.7° (*c* 0.69, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.41 (3 H, s), 3.74 (1 H, sextet, *J* = 7, 4, 4 Hz), 4.33 (1 H, dd, *J* = 10, 7 Hz), 4.44 (1 H, d, *J* = 4 Hz), 4.66 (1 H, dd, *J* = 10, 4 Hz), 6.80–7.62 (14 H).

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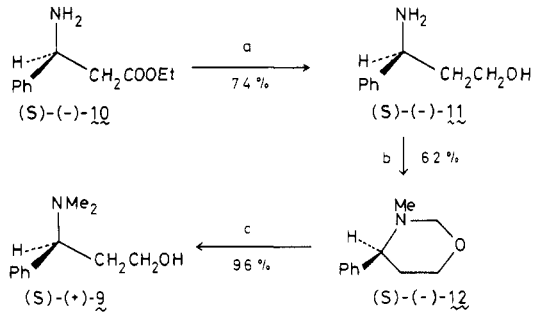
Scheme III



[a] $LiAlH_4$-Et_2O, 0 °C. [b] CH_2=O-HCOOH. [c] $LiAlH_4$-$AlCl_3$-Et_2O, 0 °C.

indicating that both compounds possess the same relative stereochemistry[10] with respect to the C-3 and C-4 substituents, and hence they are diastereomeric due to S=O chirality. The reaction of *C*-phenyl-*N*-methylnitrone (**3**) with the sulfoxide (+)-**1** in refluxing benzene for 15–20 h also yielded 4-(*p*-tolylsulfinyl)isoxazolidines **6a** and **6b**[11] in 36% and 4% yields, respectively,[12] which were again diastereomeric for S=O.

For determination of the degree of the chiral induction in the above cycloadditions, the mixture of **4a,b** was subjected to reductive N–O bond cleavage followed by the reductive removal of *p*-tolylsulfinyl group to afford in 47% overall yield 3-anilino-3-phenyl-1-propanol (**7**): mp 81 °C;[13] $[\alpha]^{25}_D$ + 41° (*c* 0.25, $CHCl_3$). The amino alcohol **7** was then N-methylated with CH_2=O and $NaBH_3CN$ to give in 89% yield 3-(*N*-methylanilino)-3-phenyl-1-propanol (**8**): bp 165–175 °C (0.3 torr); $[\alpha]^{23}_D$ +209° (*c* 0.43, $CHCl_3$). The enantiomeric excess of **8** was determined as more than 90% by using the chiral NMR shift reagent Eu(hfc)$_3$.

A mixture of **6a,b** was converted to (–)-3-(dimethylamino)-3-phenyl-1-propanol [**9**: bp 110–120 °C (13 torr); $[\alpha]^{25}_D$ –40° (*c* 0.40, $CHCl_3$)] by N-methylation, reductive N-O cleavage, and desulfurization as sequence of reactions shown in Scheme II. The optical purity of **9** was determined as no less than 80% by use of Eu(hfc)$_3$. The absolute configuration of (–)-**9** was determined as *R* by the comparison of the optical rotation with (*S*)-(+)-**9** which was obtained from (–)-β-phenyl-β-alanine ethyl ester[14] by the reactions shown in Scheme III.[15] Thus the absolute configuration at C-3 in **6a** and probably in **4a** was assigned as the *S* configuration.

Although the present study is limited to the reactions with only two acyclic nitrones,[17] the remarkably high chiral induction observed is sufficient to suggest the potential use of **1** as the chiral inducing agent in cycloadditions. Mechanistic studies concerning the steric course of the 1,3-dipolar cycloaddition and the application of **1** to other cycloadditions are now in progress in this laboratory.

Registry No. **1**, 54828-68-1; **2**, 1137-96-8; **3**, 3376-23-6; **4** (isomer 1), 82769-67-3; **4** (isomer 2), 82769-68-4; **5**, 82769-69-5; **6** (isomer 1), 82769-70-8; **6** (isomer 2), 82769-71-9; **7**, 82769-72-0; **8**, 82769-73-1; (*R*)-(–)-**9**, 82769-74-2; (*S*)-(+)-**9**, 82769-75-3; (*S*)-(–)-**10**, 3082-69-7; (*S*)-(–)-**11**, 82769-76-4; (*S*)-(–)-**12**, 82769-77-5; 3-anilino-2-[(4-methylphenyl)sulfinyl]-3-phenyl-1-propanol, 82769-78-6; 3-(dimethylamino)-2-[(4-methylphenyl)sulfinyl]-3-phenyl-1-propanol, 82769-79-7; 3-(dimethylamino)-2-[(4-methylphenyl)thio]-3-phenyl-1-propanol, 82769-80-0.

(9) MCPBA oxidation of **5** gave a mixture of **4a,b**.

(10) Although NMR data for both **4** and **6** ($J_{3,4}$ = 3–6 Hz) suggest the trans configuration, the chemical confirmation should be the subject of further investigation. Base-catalyzed isomerization experiments (e.g., *n*-BuLi, LDA) failed due to the decomposition of the isoxazolidines.

(11) **6a**: mp 100–101 °C (*n*-hexane): TLC R_f 0.25(AcOEt-n-hexane 1:1); $[\alpha]^{25}_D$ +227° (*c* 0.21, $CHCl_3$); ^1H NMR ($CDCl_3$, 200 MHz) δ 2.36 (3 H, s), 2.66 (3 H, s), 3.70 (1 H, m), 4.0 (1 H, d, *J* = 6 Hz), 4.25 (2 H, m), 7.0–7.7 (9 H). **6b**: mp 112–113 °C (*n*-hexane): TLC R_f 0.33 (AcOEt–*n*-hexane, 1:1); $[\alpha]^{23}_D$ +47.7° (*c* 1.43, $CHCl_3$); ^1H NMR ($CDCl_3$, 200 MHz) δ 2.38 (3 H, s), 2.62 (3 H, s), 3.60 (m, 2 H), 4.10 (1 H, m), 4.5 (1 H, dd, *J* = 9, 3 Hz), 7.2–7.6 (9 H).

(12) 2-Methyl-3-phenyl-4-isoxazoline was isolated as a very minor product.

(13) M. E. Speeter and W. H. Maroney, *J. Am. Chem. Soc.*, **76**, 5810 (1954).

(14) (a) E. Graf and H. Boeddeker, *Justus Liebigs Ann. Chem.*, **613**, 111 (1958). (b) M. Pais, R. Sarfati, and F.-X. Jarreau, *Bull. Soc. Chim. Fr.*, **1973**, 331. (c) Hydrolysis of (–)-β-phenyl-β-alanine ethyl ester afforded (*S*)-(–)-β-phenyl-β-alanine: mp 232 °C; $[\alpha]^{25}_D$ –9.6° (*c* 0.82, H_2O).

(15) (–)-β-Phenyl-β-alanine ethyl ester (**10**): bp 140–150 °C (16 torr) [lit.[14a] bp 148–149 °C (13 torr)]; $[\alpha]^{22}_D$ –2.4° (*c* 0.13, EtOH) (lit.[14a] –3.6°). (–)-3-Amino-3-phenyl-1-propanol (**11**): bp 90–100 °C (0.13 torr); $[\alpha]^{23}_D$ –2.8° (*c* 0.57, EtOH). (–)-3-Methyl-4-phenyltetrahydro-1,3-oxazine (**12**): bp 110–120 °C (14 torr); $[\alpha]^{24}_D$ –49° (*c* 0.11, $CHCl_3$). (+)-3-(Dimethylamino)-3-phenyl-1-propanol (**9**): bp 115–125 °C (14 torr); $[\alpha]^{24}_D$ + 24.2° (*c* 0.07, $CHCl_3$).

(16) It should be noted that **4a** and **6a** have the *S* notation because of the change in priority of the substituents on the chiral carbon atom.

(17) As preliminary experiments, the reaction of several *N*-methyl-*C*-arylnitrones have been performed, and a comparable order of diastereoselectivity was observed. The reactions of **1** with some cyclic nitrones are now underway. All combined results will be reported elsewhere in the near future.

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Complete Regio- and Stereospecificity in the Lewis Acid Catalyzed Diels–Alder Reactions of (*Z*)-2-Methoxy-1-(phenylthio)-1,3-butadienes. Conversion of the CS Configuration of an Adduct to the CC Configuration at the Allylic Position by a [2,3] Sigmatropic Rearrangement[1]

Summary: Three dienes of the indicated type react with methyl vinyl ketone (MVK) and with 2-cyclohexen-1-one under catalysis by magnesium bromide or ethylaluminum dichloride to provide good yields of only the endo adducts in which the regiochemistry is completely controlled by the sulfur atom; the acetyl group of one of the adducts with MVK has been converted to an isopropenyl group and the product treated with diethylzinc/methylene iodide to give, by a [2,3] sigmatropic rearrangement, a material in which a quarternary carbon atom has been generated in a predictable configuration at the allylic position with respect to the phenylthio group.

Sir: Since its introduction in 1974,[2a] Danishefsky's diene, the readily prepared *trans*-1-methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene, has proved to be particularly useful in synthesis.[2b] Other dienes bearing two heteroatom substituents[3] which have recently been added to the repertoire of the synthetic chemist include the (*E,E*)-1-oxygenated-4-(phenylthio)- and the 2-oxygenated-3-(phenylthio)-1,3-butadienes of Trost[4] and the (*Z*)-2-methoxy-

(1) Taken in part from the Ph.D. Thesis of Z.K., University of Pittsburgh, 1981.

(2) (a) Danishefsky, S.; Kitahara, T. *J. Am. Chem. Soc.* **1974**, *96*, 7807. (b) Danishefsky, S. *Acc. Chem. Res.* **1981**, *14*, 400.

(3) Review of Diels–Alder reactions of heterosubstituted 1,3-dienes: Petrzilka, M.; Grayson, J. I. *Synthesis* **1981**, 753.

(4) Trost, B. M.; Ippen, J.; Vladuchick, W. C. *J. Am. Chem. Soc.* **1977**, *99*, 8116. Trost, B. M.; Vladuchick, W. C.; Bridges, A. J. *Ibid.* **1980**, *102*, 3548, 3554.

0022-3263/82/1947-4005$01.25/0