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ASYMMETRIC OXIDATION OF ACHIRAL SELENIDES TO OPTICALLY ACTIVE SELENOXIDES. STEREOCHEMISTRY OF THE ALLYL SELENOXIDE-SELENENATE [2,3] SIGMATROPIC REARRANGEMENT.

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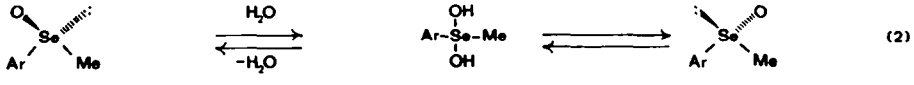
Abstract-Asymmetric oxidation of methyl phenyl selenide (3), under anhydrous conditions, by chiral 2-sulfonyloxaziridines, 1-2, gives optically active methyl phenyl selenoxide (8.1-9.3% ee). The stereochemistry of the selenoxide is determined by the configuration of the oxaziridine three membered ring with non-bonded steric interactions responsible for the chiral recognition. Asymmetric oxidation of E-phenyl cinnamyl selenide (7) by 1-2 affords optically active 1-phenylallyl alcohol (9). A concerted [2,3] sigmatropic rearrangement via an exo transition state is proposed.

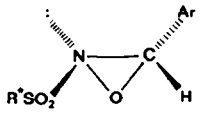
Optically active sulfoxides (ArS(O)R) are valuable synthetic intermediates, having played important roles in mechanistic studies and in understanding the origins of asymmetric induction.[2] Many procedures have been devised for their preparation including the asymmetric oxidation of achiral sulfides.[3] Optically active selenoxides (ArSe(O)R) are rare despite numerous attempts to prepare them.[4,5] Diastereomeric selenoxides, prepared by oxidation of steroidal selenides, have been reported by Jones[4b] and by Back[4c]. A recent attempt to prepare optically active selenoxides by microbial oxidation of achiral selenides failed.[4d] To date there are no examples of the asymmetric oxidation of achiral selenides to optically active selenoxides.

Recently we described the first synthesis of simple optically active selenoxides (ArSe(O)Me, Ar=Ph, 2,4,6-isopropylphenyl) by kinetic resolution of racemic selenoxides using optically active sulfonamides ($R^*SO_2NH_2$) (eq 1).[5] It was demonstrated that the configurational lability of the selenoxide moiety is the result of acid catalyzed hydrate formation (eq 2). While (-)(S)-methyl phenyl selenoxide ($[\alpha]_D$-2.5°, 10.0% ee) was racemized in less than 10 seconds by trace amounts of water, (-)(S)-2,4,6-triisopropylphenyl selenoxide ($[\alpha]_D$-8.6, %5.6 ee) was stable in the presence of water for several days.[5] These results suggest the feasibility of preparing simple optically active selenoxides by asymmetric oxidation of achiral selenides, provided that the oxidation and isolation are carried out under rigorously anhydrous conditions, in the absence of acid.

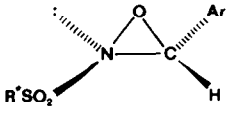


Previous studies from these laboratories have demonstrated the utility of chiral 2-sulfonyloxaziridines 1 and 2 for preparing optically active sulfoxides[3a-b] and epoxides.[6] Because of their well defined active sites these reagents are also important in exploring the origins of asymmetric induction in oxygen-transfer reactions. It has been established that the product stereochemistry is determined by the configuration of the oxaziridine three-membered ring and that

non-bonded steric interactions in the transition state are responsible for the chiral recognition.[3,6] Thus, oxidation of sulfides to sulfoxides using (-)-(S,S)-1 and (+)-(R,R)-2 gives, in every case, the (-)-S and (+)-R-sulfoxides, respectively, in 5-8 times the enantioselectivity exhibited by chiral peracids.[3] The fact that 2-sulfonyloxaziridines are aprotic and neutral oxidizing reagents suggest their application in preparing optically active selenoxides.



(-)(S,S)-1



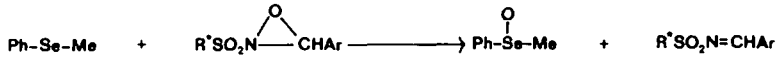
(+)(R,R)-2

a) R^*= d-10-camphor b) R^*= d-α-bromo-π-camphor

Ar= 2-chloro-5-nitrophenyl

We now report the first examples of the asymmetric oxidation of achiral selenides to optically active selenoxides and their utility in understanding the stereochemistry of the allyl selenoxide-selenenate [2,3] sigmatropic rearrangement.

Asymmetric Oxidation of Methyl Phenyl Selenide. Asymmetric oxidation of methyl phenyl selenide (3) was accomplished by adding equimolar solutions of (-)-(S,S)-1a or (+)-(R,R)-2a ($CDCl_3$) to 3 in a dry NMR tube purged with argon. Oxidation was complete within a few minutes, affording a quantitative yield of methyl phenyl selenoxide (4) and sulfonimine 5. The extent of the asymmetric induction was determined by adding to solution successive amounts of tris[3-(heptafluoropropylhydroxymethylene d-camphorato]-europium (III), $Eu(hfc)_3$. When the separation of the methyl protons in 4 was 12-14 Hz the signal was also unobscured by the protons of the camphor ring. The asymmetric induction for oxidation of 3 by (-)-1a and (+)-2a was determined to be 9.0% ee and 8.5% ee, respectively (Table I).



3 1–2 4 5

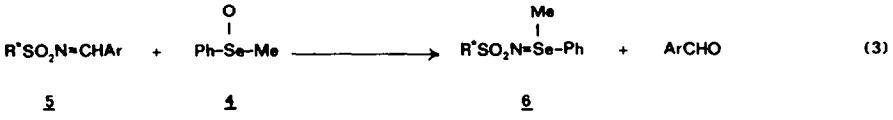
As expected, attempts to isolate optically active 4 by chromatography were unsuccessful affording only racemic selenoxide, 4. Undoubtedly the reason for this is the configurational lability of this selenoxide in the presence of moisture and acid.[5] The chiral selenoxide is separated from the sulfonimine, 5, by carrying out the oxidation in a sublimation receiver. After removal of the solvent, using a stream of dry argon gas, the residue is sublimed at 60 °C (0.01 mm) for three hours. After the sublimation is complete the sublimator is place in a glove bag (dry argon atmosphere) where all transfers take place. The sublimate consists of both selenoxide 4 (55%) and 2-chloro-5-nitrophenylbenzaldehyde (45%) as determined by NMR. The sign of rotation as well as the absolute configuration of 4 is obtained on the mixture. The absolute configuration is determined using Pirkle's solvent, (+)-2,2,2-trifluoro-1-(9-anthryl)ethanol.[5] These results are summarized in the Table I.

In the presence of sulfonimine 5, methyl phenyl selenoxide (4) reacts on heating to give 2-chloro-5-nitrobenzaldehyde and selenimide 6 in good yield (eq 3). Although a satisfactory elemental analysis for 6 could not be obtained, due to its hygroscopic nature,[7] its structure is fully consistent with its IR, NMR and EI-MS. The NMR spectrum of 6 displays a singlet at 2.75 for the Se-Me group and IR absorption at 1730 (C=O), and 1240 and 1100 cm^{-1} (SO_2). A molecular ion for 6 is observed at m/z 401 and a base ion at m/z 178. Selenimide, 6, was prepared independently in 77% yield by heating equivalent amounts of 4 and d-10-camphorsulfonamide in benzene .[5]

TABLE I: ASYMMETRIC OXIDATION OF SELENIDES USING CHIRAL OXAZIRIDINES 1-2.

entry	Oxaziridine	Solvent/ Temp. °C	Selenide	%Yield[a]	Product %Ee (Configuration)
			PhSeMe (3)		PhSe(O)Me (4)
1	(-)(S,S)-1a	$CHCl_3$/ 25°		20	(9.3)[b] (8.8)(S)[c]
2	(+)(R,R)-2a	$CHCl_3$ 25°		18	(9.1)[b] (8.1)(R)[c]
			PhSe, Ph (7)		OH, Ph (9)
3	(-)(S,S)-1a	THF[d] 0-5°		61	8.6 (S)[e]
4	(-)(S,S)-1a	THF[d] -37°		63	8.8 (S)[e]
5	(-)(S,S)-1a	THF[f] 0-5°		62	8.6 (S)[e]
6	(+)(R,R)-2b	THF[d] 0-5°		51	12.8 (R)[e]

a) Isolated yield. Reactions were carried out at least twice and the results averaged.
b) Configuration determined using (+)-2,2,2-trifluoro-1-(9-anthryl)ethanol on the reaction mixture.
c) Configuration determined using (+)-2,2,2-trifluoro-1-(9-anthryl)ethanol on the isolated sample.
d) Anhydrous THF.
e) Enantiomeric excess (%e.e.) determined by comparision with Figure 1.
f) Aqueous THF/Pyridine



(3)

R*= (+) or (-)-camphor, Ar= 2-chloro-5-nitrophenyl

The reaction sequence shown in Reaction 3 can be used to prepare optically active selenoxides, 4 by kinetic resolution. Thus heating (+)-5 and (-)-5 with 2.0 equivalents of racemic methyl phenyl selenoxide (4) affords (-)-(S)-4 (6-8% ee) and (+)-(R)-4, (7% ee) respectively, after isolation by sublimation. Kinetic resolution of selenoxides using chiral sulfonimines, 5, (eq 3) is not practical because the product is always contaminated with the aldehyde. The best method for preparing optically active selenoxides is shown in Reaction 1.[5]

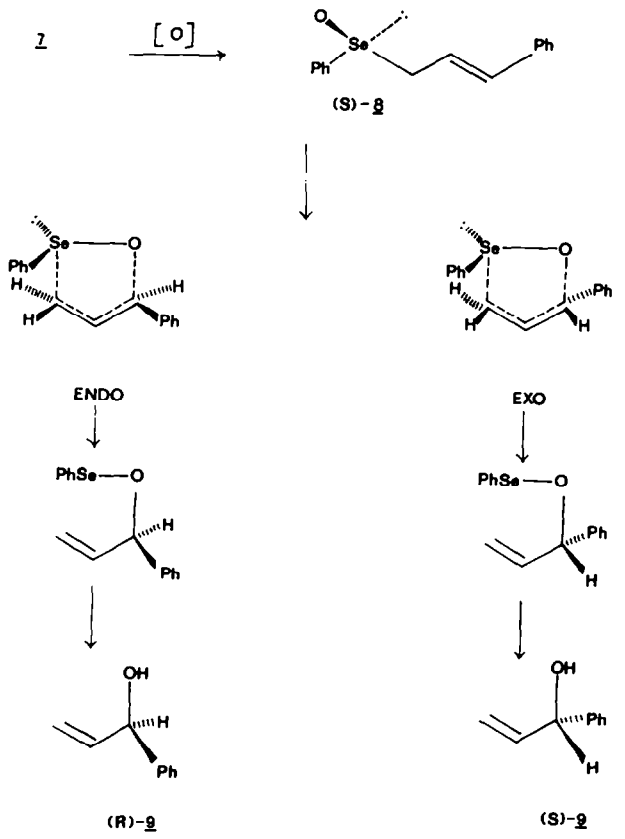
As observed for the asymmetric oxidation of sulfides to sulfoxides by 1-2, the configuration of the oxaziridine three-membered ring controls the product stereochemistry.[3] Thus (-)-(S,S)-1a, affords (-)-(S)-methyl phenyl selenoxide (4) while (+)-(R,R)-2a gives (+)-4 having the R-configuration. These results argue convincingly for similar mechanisms of chiral recognition for sulfide to sulfoxide and selenide to selenoxide asymmetric oxidations, namely an S_N2 type attack by the nucleophile (S or Se) on the electrophilic oxaziridine oxygen atom. The lower asymmetric induction observed for the oxidation of 4 compared to methyl p-tolyl sulfide (8 vs 17 % e.e.) is probably related to the longer C-Se and Se-O bond lengths in the former. Longer bond lengths may

reduce the magnitude of the steric interactions in the diastereomeric transition states that govern the asymmetric induction.

Stereochemistry of the Allyl Selenoxide-Selenenate [2,3] Sigmatropic Rearrangement. The reversible allyl sulfenate-sulfoxide [2,3] sigmatropic rearrangement, Scheme 1 (Se=S), discovered by Mislow and co-workers,[8] has been investigated by several groups.[9-11] For sulfoxides the reaction is considered to proceed through a five-membered cyclic transition state by a doubly suprafacial migration.[8-10] The equilibrium lies strongly to the left in favor of the sulfoxide. Based on the low stereoselectivity observed for rearrangement of E-sulfoxides the energy difference between the endo and exo-transition states (Scheme 1, Se=S) has been estimated at only 0.5-1.0 kcals/mole and is dependant on the structure of the sulfoxide-sulfenate.[9-10] An exo-transition state, for example, is favored for rearrangement of α-methylallyl p-toluenesulfenate to E-but-2-enyl p-toluene sulfoxide,[9] while an endo-transition state is favored for rearrangement of (+)-(R)-E-2-octenyl-p-tolylsulfoxide to (-) (R)-octen-3-ol.[10]

For selenoxides, the equilibrium shown in Scheme 1 lies overwhelmingly toward the selenenate (PhSe-O-R). Thus, in the oxidation of allyl selenides allyl selenoxides are rarely observed rearranging at low temperatures (-80 to -30 °C) to allyl selenenates (Scheme 1).[11-14] The corresponding allyl selenenates are also quite labile, decomposing rapidly to allylic alcohol under hydrolytic conditions (Scheme 1). The only stereochemical study of the selenoxide-selenenate [2,3] sigmatropic rearrangement is that by Reich and co-workers.[11] In a study of the rearrangement of o-nitrophenyl prenyl selenoxide to the selenenate, they estimated an exo-endo transition energy of 2.0 kcal/mole based upon the corresponding sulfur system. It was not possible from these results to say whether the exo or endo transition state was lower in energy.[11]

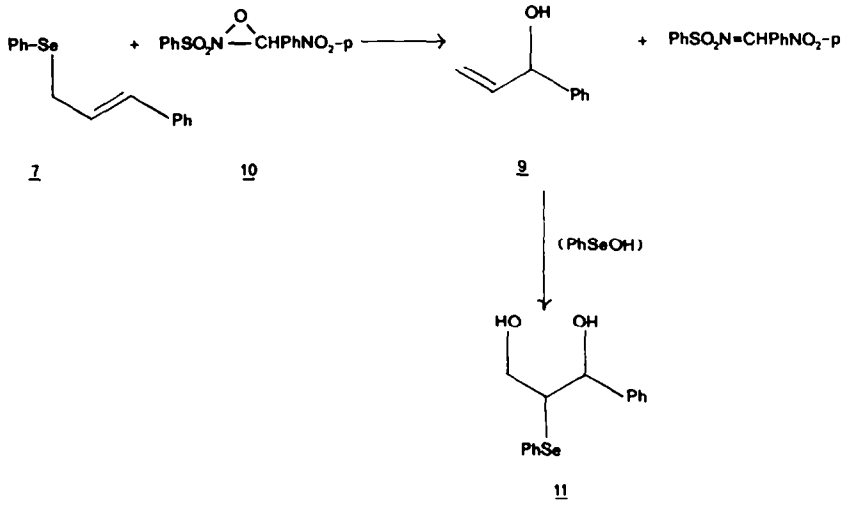
SCHEME 1



The availability of an optically active allylic selenoxide should provide a more precise picture of the transition state geometry for the allyl selenoxide-selenenate [2,3] sigmatropic rearrangement. For example, (S)-phenyl cinnamyl selenoxide (8) would afford (S)-1-phenylallyl alcohol (9) via an exo-transition state and (R)-9, via an endo transition state (Scheme 1), provided that the intermediate selenoxide, 8, is configurationally stable under the reactions conditions and a concerted [2,3] sigmatropic rearrangement is involved.

E-Phenyl cinnamyl selenide (7) was prepared in greater than 80 % yield by treatment of trans cinnamyl chloride with sodium phenyl selenenate. The trans structure of 7 was confirmed by both gc/ms and high field (360 mHz) proton NMR. Consistent with the E-structure of 7 is the trans coupling constant of 15.6 Hz for the decoupled vinyl proton signal centered at δ6.3 ppm.

The initial oxidation of 7, by 2-benzenesulfonyl-3-(p-nitrophenyl)oxaziridine (10), produced 1-phenyl-2-phenylseleno-1,3-propanediol (11) in 45% isolated yield with the desired allylic alcohol, 9, being isolated in only 25% yield.[15] This diol, 11, results from addition of benzeneselenenic acid (PhSeOH) to the allylic alcohol 9. Its structure is supported by satisfactory elemental analysis, IR and NMR spectra.[15] The methylene protons appear as a doublet (J= 4Hz) at δ3.72 ppm and the methine proton, adjacent to the phenylselenyl group, as a quintet at 3.4-6.6 (J= 3 Hz). The fact that these chemical shifts are similar to those reported for the related 4-phenylselenyl-3,5-dihydroxyoctane[16] is additional support for the structural assignment. Selenodiol 11 was prepared independently in greater than 60% isolated yield by reaction of 1-phenylallyl alcohol (9) with diphenyl diselenide, phenyl seleninic acid and water.[16]



The electrophilic addition of PhSeOH to alkenes is a side reaction in the rearrangement of allylic selenoxides to allylic alcohols and the syn elimination of selenoxides to alkenes.[17] It can be supressed by using a large excess of the oxidizing reagent or adding alkyl amines to the reaction mixture. Since 2-sulfonyloxaziridines are inert to pyridine, this troublesome side reaction can be completely eliminated simply by carrying out the oxidation in the presence of excess pyridine. Oxidation of 7 by 10 in THF followed by addition of aqueous pyridine gave 9 in 88 % yield with none of the diol 11 being detected.[15]

Asymmetric oxidation of E-phenyl cinnamyl selenide (7) was accomplished by reaction with one equivalent of (-) (S,S)-1a or (+)-(R,R)-2b in THF solution. After 5 min, 1 mL of water containing 0.5 mL of pyridine was added and the reaction mixture stirred for 6 hours at room temperature. The solvent was removed, dissolved in chloroform and 1-phenyl allyl alcohol (9) isolated by preparative TLC (silica gel G). The alcohol thus obtained was re-chromatographed and obtained in greater than 99% purity (GLC). The optical purity and absolute configuration of the alcohol, 9, was determined

TABLE II: EFFECT OF SOLVENT ON THE OPTICAL ROTATION OF 1-PHENYLALLYL ALCOHOL (9) AT 25 °C

Solvent	Percent Conc.	Observed Rotation[a]	Reported Rotation[b]
none	neat	-10.87	+10.0
CS_2	5.007	+14.44	+12.1
PhH	5.143	+9.90	+8.2
$CHCl_3$	5.170	+3.0	+3.2
EtOH	5.350	-2.40	-2.2

a) Rotation measured in a one decimeter cell and doubled.
b) Values of Duveen and Kenyon[18] taken in a two decimeter cell. These values were erroniously reported to (+)-9 neat.

by comparing its optical rotation with that of a standard curve (vide infra) (Table I). Lowering the temperature or carrying out the oxidation in the presence of aqueous pyridine had no influence on the asymmetric induction or configuration of the allylic alcohol, 9 (Table I: entries 3 and 4).

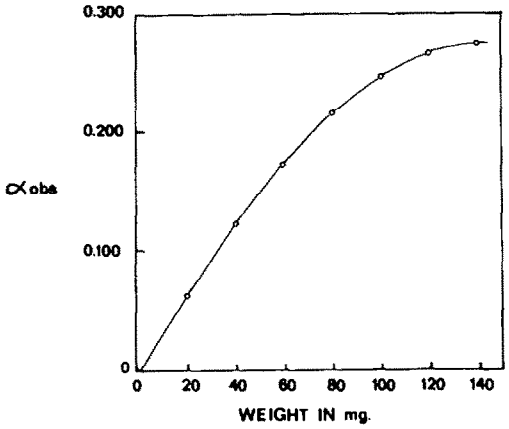
Several conclusions may be drawn from the results summarized in Table I. First, the fact that optically active 9 was obtained on asymmetric oxidation of 7 is consistent with a concerted stereospecific [2,3] sigmatropic mechanism for the allyl selenoxide-selenenate rearrangement (Scheme 1). Second, as observed for the asymmetric oxidation of methyl phenyl selenide (3), the configuration of the oxaziridine three membered ring controls the stereochemistry of the product alcohol. Thus (-) (S,S)-1a affords (S)-1-phenylallyl alcohol (9) while (+) (R,R)-2b affords (R)-9. Thirdly, the rearrangement of allylic selenoxides to the selenenates (Scheme 1) is very fast since the presence of water has no influence on the asymmetric induction (Table I: entry 5). The racemization of selenoxides in the presence of trace amounts of water is extremely fast (eq 2).

Based on the asymmetric oxidation studies of methyl phenyl selenide (3) to the selenoxide, 4, it is reasonable to assume that the configuration of intermediate allylic selenoxide 8, is determined by the configuration of the oxaziridine three-membered ring. Therefore, asymmetric oxidation of 7 by (-) (S,S)-1a affords (S)-allylic selenoxide, 8, while (+) (R,R)-2b gives the (R)-8. Since the (S)- and (R)-allylic selenoxides, 8, preferentially rearranged to the (S)- and (R)-1-phenylallyl alcohol (9), respectively, it is concluded that exo-transition state geometry is preferred for the allyl selenoxide-selenenate [2,3] sigmatropic rearrangement (Scheme 1). Note that the exo-transition state is thermodynamically more favorable because there are fewer non-bonded interactions between the two bulky phenyl groups than in the endo transition state (Scheme 1).

Since we have no direct knowledge of the stereoselectivity of the selenoxide-selenenate [2,3]-sigmatropic rearrangement, a definitive answer as to the energy difference between the exo and endo transition states (Scheme 1) is not possible. However, if the asymmetric bias for oxidation of 7 to 8 is similar to that observed for methyl phenyl selenide (3) it would suggest that chirality at *selenium is transferred essentially quantitatively to carbon. Note that the asymmetric induction* for oxidation of 7 to 9 is actually higher than that for oxidation of methyl phenyl selenide (3) to selenoxide, 4 (Table I). If this assumption is correct, the difference in energy between the exo and endo-transition states (Scheme 1) can be estimated to be at least 2.6 kcal/mole at 0-5 °C.

Optical Purity and Absolute Configuration of 1-Phenylallyl Alcohol (9). Attempts to determine the optical purity of 9 using chiral shift reagents ($Eu(hfc)_3$ and $Pr(Tfc)_3$), (+) 2,2,2-trifluoro-1-(9-anthryl)ethanol or a chiral Pirkle column were unsuccessful. It was necessary, to rely on the maximum reported optical rotation of 9 to determine its optical purity. 1-Phenylallyl alcohol (9) was first resolved by Duveen and Kenyon in 1939.[18] They reported a rotation for pure (-) -9 of $[\alpha]_D$-20.8° (1, 2 neat). Arcus and Strauss reported a value of $[\alpha]_D$-5.12° (1, 0.5 neat).[19] We also resolved 9 and recorded a value for the negative enantiomer of $[\alpha]_D$-10.872° (1, 1.0 neat). That this latter value is a reliable measure of the maximum rotation for optically pure 9 was confirmed by

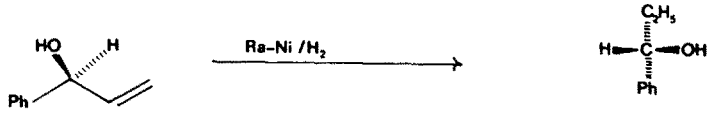
FIGURE 1: OPTICAL ROTATION OF 1-PHENYLALLYL ALCOHOL VERSUS CONCENTRATION (MG) IN $CHCl_3$ AT 25 °C



converting it into a diastereomeric carbamate using (+) (R)-α-methylbenzyl isocyanate.[25] Proton NMR of the carbamate indicated that 9 was greater than 99% optically pure.

The influence of concentration and solvent on the optical rotation of (-)-9 (neat) is summarized in Figure 1 and Table II, respectively. As can be seen from these results (Figure 1 and Table II) both the sign and magnitude of the rotation of chiral 1-phenylallyl alcohol (9) are solvent and concentration dependent. We noted, when comparing our values with those of Duveen and Kenyon[18] for the same solvents, that they had erroneously ascribed the values of (+)-9 (neat) to (-)-9 (neat) (Table II). The values for the enantiomeric excesses (% ee) reported in Table I for 9, are calculated from the standard curve shown in Figure 1.

Mosher and co-workers related the absolute configuration of (-) (S)-ethylphenyl carbinol (12) to (+) (S)-mandelic acid.[20] Hydrogenation of (-)-1-phenylallyl alcohol (9), $[\alpha]_D$-10.872° (1, neat), over Rainey Nickel catalyst afforded (+)-(R)-phenylethyl carbinol (12) in greater than 95% isolated yield. Based on this result (-)-9 (neat) and (+)-9 ($CHCl_3$) have the R-configuration while (+)-9 (neat) and (-)-9 ($CHCl_3$) have the S-configuration.



(-)(R)-9

(neat)

(+)(R)-12

Summary and Conclusions. The asymmetric oxidation of achiral selenides to optically active selenoxides is possible under rigorously anhydrous conditions, in the absence of acid, using chiral 2-sulfonyloxaziridine, 1-2. As observed for the asymmetric oxidation of sulfides to sulfoxides by 1-2, the selenoxide configuration is determined by the configuration of the oxaziridine three-membered ring with non-bonded steric interactions responsible for the chiral recognition. The lower asymmetric bias observed for selenoxides compared to sulfoxides is ascribed to longer bond lengths in the former.

Chirality transfer from optically active E-allyl selenoxides to allylic alcohols (eq 4) argues convincingly in favor of a concerted [2,3] sigmatropic rearrangement via an exo transition state.

Acknowledgment. We appreciate valuable discussions with Professor H. J. Reich, U. of Wisconsin. We thank Dr. C. K. DeBrosse (SKF) for the 360 MHZ nmr spectra, Mr. L. B. Killmer, Jr.(SKF) for GC/MS of 7, J. M. Billmers for preparing diol 11 and L. C. D. for technical assistance. Generous support of this work by the National Science Foundation (CHE-8114769) and Merck Sharp & Dohme are gratefully acknowledged. O. D. S. thanks the SmithKline Beckman Corporation for its fellowship award.

Experimental

Melting points were determined on a Mel-Temp apparatus and are uncorrected. ^{1}H NMR spectra were measured on Varian A-60A and JOEL FX-90Q NMR spectrometers. Optical rotations were measured on a Perkin-Elmer 241 Polarimeter. Diastereomeric oxaziridines, 1 and 2, were prepared as previously described[3] and were greater than 95% ee optically pure. 1-Phenylallyl alcohol (9) was resolved via the phthalic half ester using quinine as previously described.[18] 1-Phenylallyl hydrogen phthalate was reduced using LAH to 9 according to the procedure of Goering and Dilgren.[21] Gas chromatography was performed on a Varian 3700 gas chromatograph using a 6 ft x 1/4 in 3% OV-17 on 80/100 Supelcoport column equipped with and FID. Solvents were purified by standard methods.

Methyl Phenyl Selenide (3). In a 125 mL three necked flask equipped with magnetic stir bar, dropping funnel and nitrogen inlet was placed 3.88 g (0.0124 mol) of diphenyl diselenide (Aldrich) in 30 mL of ethanol. Added portionwise was 1.0 g (0.0264 mol) of sodium borohydride, and the reaction mixture stirred for 0.5 h at 25 °C followed by addition of 2.0 mL (4.56 g, 0.321 mol) of methyl iodide. After stirring overnight the mixture was treated with 50 mL of water and extracted with ether (2x30 mL). The combined extracts were then washed with water (4x25 mL) and dried over anhydrous $MgSO_4$. Removal of solvent afforded 3.81 g (89.9%) of a pale yellow liquid which darkens slightly on exposure to air; bp 65-70/5 torr (lit.[22] b_{760} 200-201 °C); NMR ($CDCl_3$)δ2.6 (s, 3H, Me), 7.1-7.6 (m, 5H, Ph).

E-Phenyl Cinnamyl Selenide (7). In a 125 mL three necked flask equipped with magnetic stir bar and nitrogen inlet was placed 3.9 g (0.0125 mol) of diphenyl diselenide (Aldrich) in 30 mL of absolute ethanol under a nitrogen atmosphere. Added portionwise was 1.0 g (0.0264 mol) of sodium borohydride, the reaction mixture stirred at 25 °C for 0.5 h and 3.8 g (0.025 mol) of cinnamyl chloride (Aldrich) added all at once. After stirring overnight, 50 mL of water was added and the reaction mixture extracted into chloroform (3x30 mL). The chloroform extracts were combined, washed with water (4x25 mL) and dried over anhydrous $MgSO_4$. Removal of the solvent *in vacuo* gave a solid residue which was crystallized from pentane-ether to yield 5.46 g (80%) of 7 as a white solid mp 63-65 °C (lit.;[23] mp 64-5 °C). Selenide 7 had the following properties: NMR ($CDCl_3$)δ3.70 (d, J=6 Hz, 2H, CH_2) 6.2-6.4 (m, 2H, vinyl) and 7.1-7.5 (m, 10H, Ph); a 360 MHz spectrum of the 6.2-6.4 vinyl region was resolved into a clean AB quartet (J=15.6 Hz) on irradiation of the allyl signal at 3.7; CI-MS, (NF_3 reagent gas) m/z 273 (100, M-H) 168 (9, M-C_8H_9) 157 (4.9, PhSe).

Methyl Phenyl Selenoxide (4). In a 10 mL single necked round bottom flask equipped with magnetic stirring bar was placed 0.171 g (0.001 mol) of methyl phenyl selenide (3) in 5 mL of chloroform. The solution was cooled in a ice bath and 0.31 g (0.001 mol) of 2-benzenesulfonyl-3-(p-nitrophenyl)oxaziridine (10)[26] added portion wise. After 5 min the volume was reduced to about 2-3 mL and the precipitated sulfonimine ($PhSO_2N$=CHPh-NO_2-p) removed by filtration (approximately 80% is recovered). The solvent was removed under vacuum and the semi-solid residue chromatographed on TLC (silica gel g) developing with 10% ether-pentane to afford 0.18 g (97%) of 4 as a white solid; mp 55-56 °C (lit.;[24] mp 53-4°). Selenoxide, 4, is hygroscopic, rapidly forming an oil in the presence of moisture. Hydrated selenoxide, 4, could be rendered analytically pure by dissolving in benzene and removing water by azeotropic distillation, followed by sublimination at 60 °C/0.1 torr. Methyl phenyl selenoxide (4) had the following properties: IR (thin film) 800 cm^{-1} (Se=O); nmr ($CDCl_3$)δ 2.60 (s, 3H, Se(O)Me) and 7.3-7.8 (m, 5H).

Asymmetric Oxidation of Methyl Phenyl Selenide (3). All transfers were carried out in an I^{2}R Glove Bag containing a dry nitrogen atmosphere. NMR Tube Oxidation. In an oven dried NMR tube was placed 0.050 g (0.00029 mol) of 3 dissolved in $CDCl_3$ (pre-dried for several h over 4A° molecular sieves). To the NMR solution was added via syringe, 0.12 g (0.00029 mol) of oxaziridine 1a or 2a dissolved in approximately 0.5-1.0 mL of dried $CDCl_3$. The oxidation was complete, by NMR, in less than 2 min affording a quantitative yield of 4 and camphorsulfonimine, 5.

Addition of successive amounts of $Eu(hfc)_3$ shifted the methyl doublet (enantiomers) of 4 away from the camphorsulfonimine, 5, protons. When the separation of the methyl doublet in 4 was approximately 12-14 Hz the enantiomeric excess (% ee) was determined by integration.

Isolation of chiral 4. In a 20 mL sublimation flask, under an atmosphere of dry argon was placed 0.15 g (0.00088 mol) of 3 in 1 mL of $CHCl_3$ dried over 4A molecular sieves. Added dropwise via syringe was a solution of 0.36 g (0.0008 mol) of 1a or 2a in 1 mL of $CHCl_3$, previously dried for 1 h over 4A molecular sieves. After 5 min, the solvent was removed by entrainment with argon, followed by sublimation of the residue, first at 20 torr and then at 55-60 °C at 0.05 torr for 4 hr. The sublimation apparatus was isolated from the vacuum by means of a high vacuum stopcock attached to the sublimator receiver. The water condenser was flushed with acetone, dried with an argon stream and placed in the glove bag. After 1 h the sublimator was vented to the glove bag atmosphere and the sublimate transferred, using dry $CHCl_3$ or $CDCl_3$, into either a 1.0 mL volumetric flask (for rotation) or an NMR tube.

An NMR spectrum of the sample indicated that sublimate consisted of 2-chloro-5-nitrobenzaldehyde (45%) and methyl phenyl selenoxide (5) (55%). After removal of the solvent the yield of 4 was calculated to be 18-20%. In another experiment $Eu(hfc)_3$ was added to the NMR tube and the enantiomers excess (%e.e.) determined. In another experiment the configuration of chiral 4 was determined by addition of (+)-2,2,2-trifluoro-1-(9-anthryl)ethanol. Increasing concentrations of this chiral reagent, when added to (-)-4 in $CDCl_3$, resulted in splitting of the Me signal into a doublet (maximum 10-14 Hz) along with an upfield shift in the position of the major enantiomer corresponding to the S-configuration.

(+) N-(methylbenzeneselenide)-d-10-camphorsulfonimide (6). The sublimation residue obtained from oxidation of 3 by (-) (S,S)-1a was crystallized from benzene to give 0.18 g (56%) of a white solid, mp 133-6 °C (benzene); selenimide (+)-6 had the following properties: $[\alpha]_D$+18.4 (c 1.3 $CHCl_3$); NMR ($CDCl_3$) δ0.8 (s, 3H, Me), 1.0 (s, 3H, Me), 1.4-2.5 (m, 7H, camphor ring), 2.9 (s, 3H, SeMe), 2.8-3.7 (AB quartet, J=14 Hz, 2H, SO_2CH_2), 7.3-8.0 (m, 5H, Ar); IR (KBr) 1740 (C=O), 890 (Se=N) cm^{-1}; CI-MS (CH_4 reagent gas) 401 (M+H, 17%), 215 (base ion). A satisfactory elemental analysis could not be obtained.

(-) N-(methylbenzeneselenide)-d-10-camphorsulfonimide (6) was obtained from the oxidation of 3 by (+) (R,R)-1a in 64% yield and had the following properties: mp 133-4 °C (benzene); $[\alpha]_D$-15.0 (c 1.3 $CHCl_3$); NMR ($CDCl_3$) δ 0.8 (s, 3H, Me), 1.0 (s, 3H, Me), 1.4-2.5 (m, 7H, camphor ring), 2.9 (s, 3H, SeMe), 2.8-3.7 (ab quartet, J=14 Hz, 2H, SO_2CH_2), 7.3-8.0 (m, 5H, Ar); IR (KBr) 1740 (C=O), 890 (Se=N) cm^{-1}. A satisfactory elemental analysis could not be obtained.

Kinetic Resolution of Methyl Phenyl Selenoxide (4) using (+) and (-) Sulfonimines 5. In a 50 mL single necked round bottom flask equipped with a male ⅄ 14/22 joint, magnetic stirring bar, and Dean-Stark trap containing 4A molecular sieves, was placed 0.17 g (0.001 mol) of selenoxide 4, prepared as described above, in 35 mL of dry benzene. The reaction mixture was refluxed under a dry nitrogen atmosphere for 1 h at which time 0.208 g (0.0005 mol) of (+) or (-)-camphorsulfonimine 5[3a] added. After refluxing for an additional h the solvent was removed using a stream of dry argon. The reaction flask containing the residue is fitted to a sublimation receiver and the optically active (-)-4 and (+)-4 isolated as described above. All transfers were made in the glove bag. (+)-5 gave (-) (S)-4, (6-8% e.e), 36-48% yield; (-)-5 gave (+) (R)-4, (7% ee), 58% yield.

2-Phenylseleno-1,3-dihydroxyl-1-phenylpropane (11). In a dry 25 mL round bottom flask fitted with mag stirring bar was placed 1.0 g (0.0053 mol) of benzeneseleninic acid (Aldrich), and 1.65 g (0.0053 mol) of diphenyl diselenide in 10 mL of methylene chloride. The reaction mixture was cooled to 0-5 °C in an ice bath 1.0 g anhydrous $MgSO_4$ and 2 mL of water were added and the reaction mixture stirred for 0.5 h. The ice bath was removed and 0.67 g (0.005 mol) of 1-phenylallyl alcohol (9) added and the reaction mixture stirred vigorously overnight, followed by heating to 40 °c for 1 h. The solution was filtered 50 mL of ether was added, followed by washing of the ether layer with 10% K_2CO_3 solution (2x25 mL), saturated brine solution (2x50mL) and finally drying over anhydrous $MgSO_4$. Removal of the solvent under vacuum gave an orange-yellow oil which solidified on washing with n-pentane. Crystallization from cyclohexane-benzene gave 1.1 g (60%) of 11 as white needles; mp 92-94; IR (thin film) 3100-3500 cm^{-1} (OH); NMR ($CDCl_3$) δ 2.5 (s, 1H, OH, exchanges with D_2O), 3.3-3.6 (m, 1H, J=3Hz, SeCH) 3.72 (d, 2H, CH_2OH, J-4Hz), 4.95 (d, 1H, benzylic CH, J=4Hz) and 7.1-7.6 (quintet, 10

H); EI-MS; 308 (M).

Anal. Calcd. for $C_{15}H_{16}O_2Se$: C, 58.44; H, 5.19. Found: C, 58.38; H, 5.02.

Asymmetric Oxidation of E-Phenyl Cinnamyl Selenide (7). In a 15 mL flame dried three-necked round bottom flask equipped with a magnetic stirring bar, gas inlet and dropping funnel was placed 0.273 g (0.001 mol) of 7 in 5 mL of dry THF. After cooling the reaction mixture to the desired temperature (0-5 or -37 °C) 0.41 g (0.001 mol) of (-) (S,S)-1a or 0.49 g (0.001 mol) of (+) (R,R)-2b in 3 mL of dry THF was added dropwise. After the addition was complete the reaction mixture was allowed to stir for 5 min, 1 mL of water containing 0.5 mL of pyridine added and the solution stirred for 6 h at room temperature. The bulk of the solvent was removed on the rotatory evaporator, the residue dissolved in 5 mL of chloroform, dried over anhydrous sodium sulfate and filtered. The volume was reduced to about 1 mL and chromatographed on a 1000 micron silica gel G TLC plate developing with chloroform. The lower band contained 1-phenylallyl alcohol (9) and some camphorsulfonamide. A second chromatography eluting with 10% ether-chloroform gave 1-phenylallyl alcohol (9) 99% purity by glc.

Optical purity of 1-phenylallyl alcohol (9). The optical purity of 9 was determined by dividing the observed rotation, α_{obs} by the rotation for optically pure 9 at that amount (mg) obtained from the standard curve (Figure 1). (S,S)-1a, -0.019°, (85 mg), (8.6% ee); -0.019°, (81 mg), (8.8% ee); -0.018°, (82 mg), (8.6 %ee); (R,R)-2b, +0.022°, (59 mg), (12.8 %ee); Table I.

Hydrogenation of Optically Active 1-Phenylallyl Alcohol (9). In a Parr Hydrogenation apparatus 1.38 g (0.001 mol) of (-)-9, $[\alpha]_D$-10.872° (1, neat), in 200 mL of ether was hydrogenated over Rainey Nickel catalyst for 1.5 h as described by Duveen and Kenyon.[18] Removal of the solvent gave 1.3 g (95%) of (+)-(R)-phenylethylcarbinol (12), $[\alpha]_D$+25.912° (1, 1.0, neat); lit.[18] $[\alpha]_D$+13.08° (1, 0.5 neat). NMR ($CDCl_3$) δ 0.83 (t, 3H, J=7Hz), Me), 1.65 (t, J=7 Hz, 2H, CH_2), 2.82 (s, 1H, OH), 4.47 (t, J=7Hz, 1H) and 7.36 (s, 5H, Ph).

1-(Phenyl)-allyl N-(1-[1-phenyl]ethyl)carbamate. The diastereomeric cabamates of racemic and optically active 1-phenylallyl alcohol (9) were prepared according to the procedures outlined by Pirkle and Hoekstra.[26] In a 100 mL three necked flask equipped with reflux condenser, mag. stirring bar and argon inlet was placed racemic or optically active 9 (typically, 0.5 g, 3.73 mmoles) in 60 mL of dry toluene. R-(+)-α-methyl benzylisocyanate (Aldrich), 0. 55 g, 3.73 mmoles, was added to the reaction mixture via syringe and the solution heated at reflux for 65 h. A white solid was obtained on removal of the solvent and washing with n-pentane. Crystallization from hexane-benzene gave the pure carbamate (80-86% yield).

The racemic carbamate of 9 had the following properties: mp 53-55 °C; $[\alpha]_D$+37.28 (c 1.58, $CHCl_3$); IR (KBr) 3200-3500 (NH) and 1700 (CO) cm^{-1}; NMR ($CDCl_3$) δ1.414 and 1.488 (d, diastereomer-Me, J=6.7 Hz, 3H), 1.446 and 1.520 (d, diastereomer-Me, J=6.7 Hz, 3H), 4.8-5.6 (m, 4H), 6.2 (m, 2H) and 7.5 (s, 10H).

Anal. Calcd. for $C_{18}H_{19}NO_2$: C, 76.84; H, 6.81.

The optically pure carbamate of (-)-9 had the following properties: mp 72-74 °C; $[\alpha]_D$+55.79 (c 3.40 $CHCl_3$); NMR ($CDCl_3$) δ1.38 and 1.45 (d, 3H, J-6.8 Hz, Me) , 5.0 (quintet, J=8.2 Hz), 5.4 (m, 3H), 6.0-6.4 (m, 2H) and 7.4 (s, 10H).

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