acceptable than triorganotin compounds from toxicological and practical perspectives. Further work on the synthetic scope of this material is in progress.

## Experimental Section

**Materials.** 1,1,1,2,3,3,3-Heptamethyltrisilane,[41] cyclohexyl selenide,[42] cyclohexyl xanthate,[43] neophyl bromide,[44] and di-*tert*-butyl hyponitrite[45] were prepared following literature procedures. $(Me_3Si)_2Si(D)Me$ was obtained from the corresponding silyl chloride[41] and $LiAlD_4$. All other materials were commercially available and used as received.

**General Procedure for Reduction of Organic Derivatives (Table I).** A solution containing the compound to be reduced, $(Me_3Si)_2Si(H)Me$ (1.2 equiv), and AIBN (10–20%) as initiator in toluene or benzene was heated at 348–363 K for 0.5–2.5 h and then analyzed by GC. Yields were quantified by GC using dodecane or tetradecane as an internal standard.

**General Procedure for Kinetic Measurement.** *tert*-Butylbenzene containing a small amount of decane as an internal GC standard was used as solvent. In the case of neophyl bromide, benzene was used as solvent. $(Me_3Si)_2Si(H)Me$ was added at concentrations between 1.2 and 4 M, and the bromides were added in a ratio of ca. 1:20 respect to the silane. Samples of the reaction mixtures were degassed and sealed under nitrogen in Pyrex ampules and were thermolyzed or photolyzed. Reaction were initiated thermally at 313, 323, 333 (di-*tert*-butyl hyponitrite), 350, 373 (AIBN), and 393 K (*tert*-butyl perbenzoate) and photolytically at 298 K. The products of the reaction were analyzed by GC chromatography using a 15-m × 0.53-mm methyl phenyl 5% column (Quadrex) with temperature programming from 40 to 250 using a Varian 3300 chromatograph. The hydrocarbon products of interest were identified by comparison of their retention times with authentic material.

**EPR Measurements.** The $(Me_3Si)_2\dot{S}iMe$ radical was generated by photolysis of solution of di-*tert*-butyl peroxide and $(Me_3Si)_2Si(H)Me$ (1:2 v/v) at 233 K in the cavity of a Bruker ESP300 spectrometer equipped with an NMR gaussmeter, a frequency counter, and a standard variable-temperature device. A 500-W high-pressure mercury lamp was used as UV light source. The spectrum was recorded using 200 G scan width and the regions to the left and to the right of the main pattern were recorded at higher gain. The other $^{29}Si$ hfs shown in Figure 3 were taken from ref 46.

**IR and NMR Measurements.** IR and NMR spectra of $(Me_3Si)_2Si(H)Me$ were recorded on Nicolet FTIR and Varian VXR200 spectrometers. The SiH stretching frequency and coupling constant are 2075 $cm^{-1}$ and 163 Hz, respectively. The analogous data for $Me_3SiSi(H)Me_2$ and $(Me_3Si)_3SiH$ were taken from refs 47 and 48, respectively. The SiH stretching frequencies for the series $Me_{3-n}SiH_{n+1}$ were taken from ref 9, and the SiH coupling constants for the series $Me_{3-n}Si(H)Cl_n$ were taken from ref 37.

**Acknowledgment.** Financial support from the Progetto Finalizzato Chimica Fine II (CNR–Rome) is gratefully acknowledged.

**Supplementary Material Available:** Tables IV–VI giving detailed product ratios of kinetics (4 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

(41) Kumada, M.; Ishikawa, M.; Maeda, S. *J. Organomet. Chem.* **1964**, *2*, 478.
(42) Liotta, D. *Acc. Chem. Res.* **1984**, *17*, 28.
(43) Barton, D. H. R.; McCombie, S. W. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1574.
(44) Fainberg, A. H.; Winstein, J. *J. Am. Chem. Soc.* **1956**, *78*, 2763.
(45) Mendenhall, G. D. *Tetrahedron Lett.* **1983**, *24*, 451.
(46) Hesse, C.; Leray, N.; Roncin, J. *J. Chem. Phys.* **1972**, *57*, 749. Alberti, A.; Pedulli, G. F. *Rev. Chem. Interm.* **1987**, *8*, 207.
(47) Urenovitch, J. V.; West, R. *J. Organomet. Chem.* **1965**, *3*, 138.
(48) Buerger, H.; Kilian, W. *J. Organomet. Chem.* **1969**, *18*, 299.

# Highly Regioselective and Stereospecific Functionalization of 1,2-Propanediol with Trimethyl(X)silanes Employing the 1,3,2λ⁵-Dioxaphospholane Methodology

Isabel Mathieu-Pelta and Slayton A. Evans, Jr.*

*The William Rand Kenan, Jr., Laboratories of Chemistry, The University of North Carolina, Chapel Hill, North Carolina 27599-3290*

*Received January 10, 1992*

The regioselective ring opening of (*S*)-4-methyl-2,2,2-triphenyl-1,3,2λ⁵-dioxaphospholane (**2**) [prepared from the bis(transoxyphosphoranylation) of (*S*)-1,2-propanediol (**1**) with diethoxytriphenylphosphorane (DTPP)] was initiated with several trimethylsilyl reagents ($Me_3SiX$: X = PhS, I, Br, Cl, CN, and $N_3$) to afford the regioisomeric (silyloxy)phosphonium salts. A stereospecific extrusion of triphenylphosphine oxide from these oxyphosphonium salts gave predominantly the thermodynamically less stable C-2-X-substituted derivatives with nearly complete inversion of stereochemistry at the C-2 stereogenic center (i.e., X = PhS).

## Introduction

A highly regio- and stereospecific method for C-2 hydroxyl replacement in an unsymmetrical 1,2-diol [i.e., 1,2-propanediol (**1**)] in a "single synthetic event" would be of significance for effecting a host of useful synthetic transformations. Previously, we described the benzoylation of diol **1** and 2-phenyl-1,2-ethanediol with triphenylphosphine and benzoyl peroxide. The intermediate and transient 4-methyl- (**2**) and 4-phenyl-2,2,2-triphenyl-1,3,2λ⁵-dioxaphospholanes, respectively,[1] were captured with the benzoic acid, formed in situ, to afford largely the C-2 benzoate with essentially complete inversion of stereochemistry.[1] We suggested that an association (i.e., intermolecular hydrogen bonding) between the dioxaphos-

(1) (a) Pautard, A. M.; Evans, S. A., Jr. *J. Org. Chem.* **1988**, *53*, 2300–2303. (b) Pautard-Cooper, A.; Evans, S. A., Jr. *J. Org. Chem.* **1989**, *54*, 2485–2488, 4974.

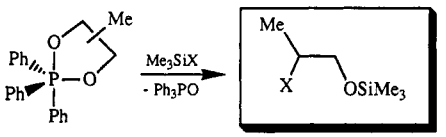
0022-3263/92/1957-3409$03.00/0 

Table I. Reactions of 1,3,2λ⁵-Dioxaphospholane 2 with Trimethyl(X)silanes

| | oxyphosphonium ions[a] | | regioisomers[b] | | |
|---|---|---|---|---|---|
| $Me_3SiX$ (reactn condns) | 3 | 4 | C-2-X | C-1-X | yield (%)[c] |
| $Me_3SiSPh$ (−78 °C, 2 h) | | | 1.6 | 1.0 | |
| $Me_3SiSPh$ (−78 °C, 18 h) | >95 | <5 | 17 | 1 | 70 |
| $Me_3SiBr$ (−78 °C, 2 h) | | | 1.6 | 1.0 | |
| $Me_3SiBr$ (−78 °C, 18 h) | 5.8 | 1.0 | 5 | 1 | 77 |
| $Me_3SiI$ (−78 °C, 1 h) | | | 4.5 | 1.0 | |
| $Me_3SiI$ (−78 °C, 18 h) | 8.7 | 1.0 | 8 | 1 | 60 |
| $Me_3SiCl$ (−78 °C, 1 h) | | | 1.2 | 1.0 | |
| $Me_3SiCl$ (−78 °C, 18 h) | 2.5[d] | 1.0 | 1.6 | 1.0 | 61 |
| $Me_3SiCN$ (−78 °C, 2 h) | | | 1.2 | 1.0 | |
| $Me_3SiCN$ (−78 °C, 18 h) | 1.9 | 1.0 | 1.9 | 1.0 | 60 |
| $Me_3SiN_3$ (25 °C, 1 h) | | | >99 | <1 | |
| $Me_3SiN_3$ (25 °C, −78 °C) | >95[e] | <5 | >99 | <1 | 85 |

[a] The relative composition ($^{31}P$ NMR) of the regioisomeric oxyphosphonium ions was not viewed as important after only 1–2 h (−78 °C) of reaction, especially considering the large excess of dioxaphospholane 2 which remained. [b] The relative distributions of the C-2-X and C-1-X regioisomers were determined using $^1H$ NMR spectral analysis of the isolated mixture of the regioisomers. [c] The yields of the "crude product mixture" varied from 92 to 99%; however, the yields reported here are isolated yields. [d] The regioisomeric distribution was derived from the integration of two broad $^{31}P$ NMR resonances which did not exhibit baseline separation. [e] Only one $^{31}P$ NMR resonance was observed and it was assigned the C-2 oxyphosphonium ion structure based on corroborative $^{13}C$ NMR data.

Scheme I. Regioselective Substitution of 4-Methyl-2,2,2-triphenyl-1,3,2λ⁵-dioxaphospholane (2) with $Me_3SiX$




2

Major or exclusive product
X = Br, I, Cl, CN, SPh and $N_3$.

pholanes and benzoic acid could adequately rationalize the regioselectivity observed in the isomeric mixture.

Employing the "proton–silicon analogy",[2] a strong oxygenophile (e.g., silyl) might be expected to promote a highly, regioselective ring opening of 4-methyl-2,2,2-triphenyl-1,3,2λ⁵-dioxaphospholane (2) to afford the regioisomeric (silyloxy)phosphonium ions with preference for the C-2 oxyphosphonium ion. In the presence of efficient, nucleophilic X counterions (e.g., X = $PhS^-$, $I^-$, $N_3^-$, etc.), the (silyloxy)phosphonium ions might be susceptible to substitution by X with the accompanying expulsion of phosphine oxide (Scheme I). As an advantage, the presence of the silyl ether in the product should certainly diminish the propensity for competitive "3-*exo*-tet"[3] alkoxide displacement of X. In principle, such a process would provide access to C-2-X derivatives of formally, 1,2-propanediol, in both a regio- and stereocontrolled manner.

Herein, we describe such a transformation involving a thermodynamically-controlled silylation of 4-methyl-2,2,2-triphenyl-1,3,2λ⁵-dioxaphospholane (2) using several trimethylsilyl derivatives ($Me_3SiX$; X = PhS, I, Br, Cl, CN, and $N_3$) to afford a predominance of the C-2 regioisomeric (silyloxy)phosphonium ion, which undergoes stereospecific nucleophilic extrusion of triphenylphosphine oxide (TPPO).

## Results and Discussion

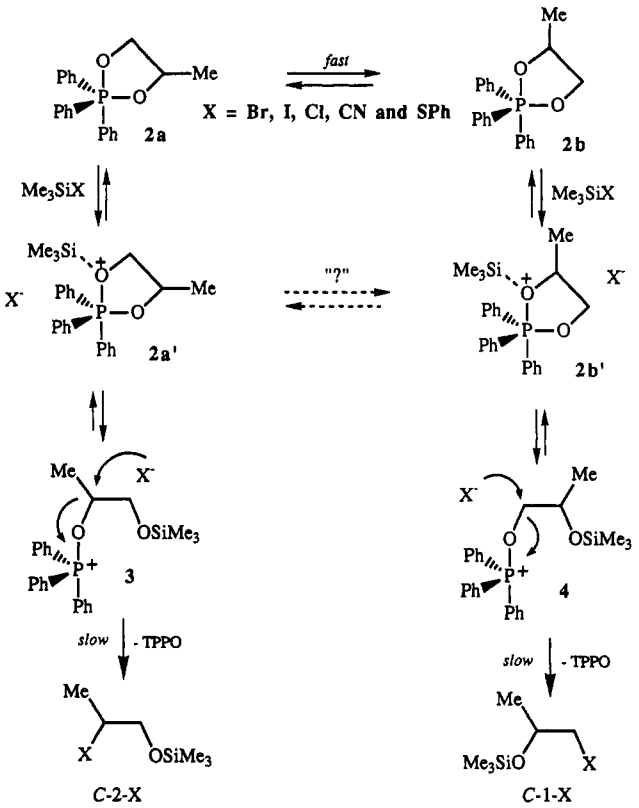
**Regioselectivity.** Dioxaphospholane 2, prepared by bis(transoxyphosphoranylation) of 1,2-propanediol (1) with DTPP,[4] was dissolved in anhydrous dichloromethane solvent and, in a series of separate experiments, allowed to react with the individual trimethylsilyl reagents ($Me_3SiX$). After 18 h at −78 °C, dioxaphospholane 2 (δ −37.2 ppm) was totally consumed and the regioisomeric (silyloxy)phosphonium ions, 3 and 4, were observed at δ 62.0 and 63.5 ppm, respectively (as monitored by $^{31}P$ NMR spectroscopy). We had previously demonstrated that the $^{31}P$ NMR resonances at δ 62.0 and 63.5 ppm are attributable to the phosphorus nuclei in the methyl ethers of oxyphosphonium ions, 3 and 4, respectively.[1,5a,b] Interestingly, the reactions involving dioxaphospholane 2 and $Me_3SiSPh$ as well as $Me_3SiN_3$ afforded only (silyloxy)phosphonium ion 3 ($^{31}P$ NMR analysis); there was no observable $^{31}P$ NMR evidence to support the presence of oxyphosphonium ion 4.

When the various reaction mixtures were warmed to ambient temperature, the C-2-X and C-1-X regioisomers were formed in 92–99% yield according to $^1H$ NMR analysis. The mixtures of C-2-X and C-1-X regioisomers were isolated in yields ranging from 60 to 85%. When similar reactions were repeated by allowing the reactions to proceed for only 1–2 h at −78 °C, the magnitude of the regioselectivity was significantly diminished (Table I).

Our tentative explanation involves a thermodynamically-governed silylation of dioxaphospholane 2 at −78 °C. By analogy with the "proton complexation" rationale previously suggested,[1a] this requires that silylation occurs at the P–O apical oxygens which exhibit enhanced basicity[5c] compared to the P–O oxygens which occupy the basal or equatorial array (Scheme II). Thus, two conformational isomers, **2a** and **2b**, which can interconvert through a Berry polytopal interchange, are important. The large silyl group attached to the P–O apical oxygen (i.e., **2b′**) is sandwiched between the C-4 methyl group and the equatorial *P*-$C_6H_5$ groups in the trigonal-bipyramidal array and is expected to experience severe steric encumbrance. It seems reasonable to assume that if equilibration between silyl adduct **1a′** and **2b′** is facile, then **1a′**, where the steric congestion created by the proximity of the methyl, silyl, and phenyl groups should be considerably diminished, should predominate. Rupture of the labile P–O apical bond leads to irreversible ring opening from −78 to 25 °C, favoring the

(2) Evans, D. A.; Truesdale, L. K.; Grimm, K. G.; Nesbitt, S. L. *J. Am. Chem. Soc.* **1977**, *99*, 5009–17.
(3) Robinson, P. L.; Barry, C. N.; Kelly, J. W.; Evans, S. A., Jr. *J. Am. Chem. Soc.* **1985**, *107*, 5210.
(4) Murray, W. T.; Evans, S. A., Jr. *J. Org. Chem.* **1989**, *54*, 2440–2446.
(5) (a) Murray, W. T.; Evans, S. A., Jr. *New J. Chem.* **1989**, *13*, 329–334. (b) We have assumed that the $^{31}P$ NMR shift differences between the phosphorus nuclei in the oxyphosphonium ions containing *O*-Me and *O*-$SiMe_3$ groups will be negligible. (c) Luckenbach, R. *Dynamic Stereochemistry of Pentacoordinated Phosphorus and Related Elements*; George Thieme: Stuttgart, FRG, 1973.

**Scheme II. Mechanistic Rationale for Regioselective Silylation of 1,3,2λ⁵-Dioxaphospholane 2**




formation of the C-2 siloxyphosphonium ion **3**. Subsequent displacement of $Ph_3PO$ by the nucleophilic counterion, X, affords the C-2-X regioisomer as the dominant product. A perusal of the data in Table I shows that in all instances the distribution of the C-2 and C-1 (silyloxy)phosphonium ions parallels the ratio of C-2-X and C-1-X regioisomers. This result is interpreted to mean that the regioselectivity is created during the relatively rapid equilibration of **2a'** and **2b'** a low temperature.

**Stereochemistry of the Substitution. Reaction between (*S*)-1,3,2λ⁵-Dioxaphospholane [(*S*)-2] and Trimethyl(phenylthio)silane.** (*S*)-1,3,2λ⁵-Dioxaphospholane [(*S*)-2] was allowed to react with $Me_3SiSPh$ for 18 h at −78 °C. The trimethylsilyl group was removed with fluoride ion (i.e., CsF) in MeOH solvent after the reaction mixture was warmed to ambient temperature. Isolation of the products was accomplished using column chromatography and gave a 70% yield of 2-(phenylthio)-1-propanol (**5**) and 1-(phenylthio)-2-propanol (**6**) in a 9:1 ratio, respectively, as determined by $^1H$ NMR analysis.

The configuration of the C-2 stereogenic center in **5** was determined as follows. Treatment of (*S*)-2 with *p*-toluenesulfonic acid (*p*-TsOH) at ambient temperature in THF solvent gave exclusively the regioisomer (*R*)-2-(((4-methylphenyl)sulfonyl)oxy)-1-propanol [(*R*)-7] in 60% isolated yield.[6] A $^1H$ NMR study using the chiral shift reagent, Eu(hfc)₃, established the enantiomeric excess as 97%. Protection of the C-1 hydroxyl group as the tetrahydropyranyl ether[7] allowed nucleophilic PhSLi displacement of the C-2 tosylate with complete inversion of stereochemistry. Removal of the tetrahydropyranyl group gave (*S*)-2-(phenylthio)-1-propanol [(*S*)-5] (Scheme III).

**Scheme III. Stereochemistry of the Substitution of (*S*)-1,3,2λ⁵-Dioxaphospholane 2 with $Me_3SiSPh$**

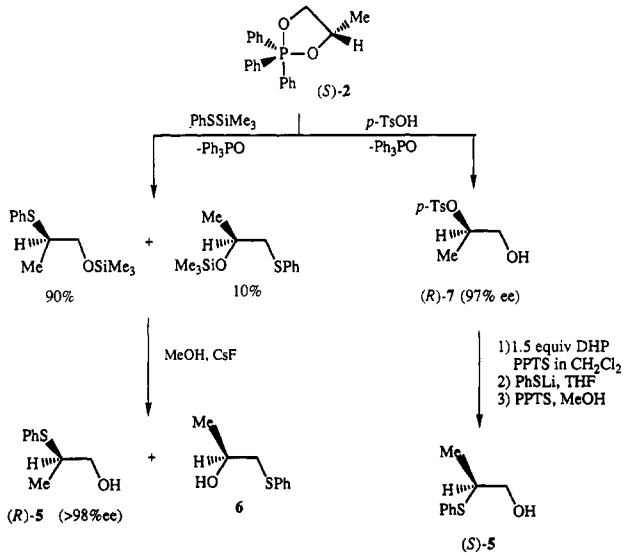
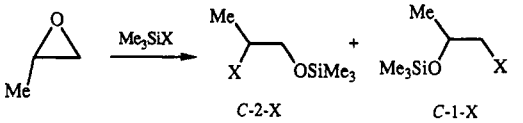



**Table II. Reactions of Propylene Oxide with Trimethyl(X)silanes**




| $Me_3SiX$ | siloxypropanes C-2-X | C-1-X |
|---|---|---|
| $Me_3SiSPh/ZnCl_2$ | 1.0 | 4.8 |
| $Me_3SiSPh/BuLi$ | 1 | 99 |
| $Me_3SiI$ | 1.0 | 3.1 |
| $Me_3SiBr$ | 1.0 | 2.7 |
| $Me_3SiCl$ | 1.0 | 2.2 |
| $Me_3SiCN/AlMe_3$ | 1 | 99 |
| $Me_3SiN_3/Ti(O\text{-}iPr)_4$ | 1 | 4 |

The direct determination of the enantiopurity of (*S*)-**5** by HPLC analysis employing the Pirkle chiral column, (dinitrobenzoyl)phenylglycine (type 1-A) was not effective. However, the peracid oxidation ($H_2O_2$/HOAc) of **5** and (*S*)-**5** gave the corresponding sulfones which were more amenable to HPLC separation. The sulfones of (*S*)-**5** and racemic **5** (*rac*-**5**) were examined separately. The HPLC analysis of the enantiomeric sulfones of **5** (from the reaction of (*S*)-**2** with $PhSSiMe_3$) indicated that this reaction occurs with essentially complete inversion (>98% ee) of configuration at the C-2 stereogenic center to afford (*R*)-**5**.

Finally, there are two other experimental observations that require comment. First, as a control, it was essential that we establish the role and significance of propylene oxide, a possible intermediate which might arise from the thermal decomposition of dioxaphospholane **2**.[8,9] Propylene oxide was allowed to react with $Me_3SiX$ in separate experiments, and the experimental conditions along with the ratios of the C-2-X:C-1-X regioisomers are reported in Table II. A comparison of these findings with those obtained from the reactions of **2** with $Me_3SiX$ strongly suggest that propylene oxide is not a viable intermediate nor precursor in these reactions. Secondly, when the reaction of dioxaphospholane **2** and $Me_3SiN_3$ was performed

(6) Pautard-Cooper, A.; Evans, S. A., Jr. *Tetrahedron* **1991**, *47*, 1603–10.
(7) Miyashita, M.; Yoshitzoshi, A.; Grieco, P. A. *J. Org. Chem.* **1977**, *42*, 3772.
(8) Robinson, P. L.; Barry, C. N.; Bass, S. W.; Jarvis, S. E.; Evans, S. A., Jr. *J. Org. Chem.* **1983**, *48*, 5380.
(9) Murray, W. T. Ph.D. Dissertation, The University of North Carolina, Chapel Hill, NC, 1989.

at *ambient temperature*, 2-azido-1-((trimethylsilyl)oxy)-propane was the exclusive product. The absence of a temperature dependence on the regiospecificity in this particular example is not well-understood and requires additional study.

## Conclusions

Nucleophilic substitutions of 1,2-propanediol (1) employing the 1,3,2λ⁵-dioxaphospholane methodology provides an attractive and synthetically useful route to C-2-X-substituted 1-propanols in good yields with high regioselectivity, and in the case of (*S*)-2-(phenylthio)-1-propanol, excellent stereospecificity is also realized.

## Experimental Section

All $^1H$, $^{13}C$, and $^{31}P$ NMR spectral data were obtained on the Bruker-IBM-200 NMR spectrometer using tetramethylsilane ($Me_4Si$) as the internal refrence for $^1H$ and $^{13}C$ NMR and 85% phosphoric acid ($H_3PO_4$) as the external reference for $^{31}P$ NMR. The HPLC analyses were performed using a Pirkle chiral column, (dinitrobenzoyl)phenylglycine (ionic, type 1-A). Commercially-available 1,2-propanediol was purified by distillation. The preparations of DTPP[3] and (*S*)-(+)-1,2-propanediol[3] have been reported elsewhere. *p*-Toluenesulfonic acid monohydrate (*p*-TsOH·$H_2O$) was dried (90 °C, 12 h) under high vacuum. Trimethylsilyl chloride, bromide, iodide, cyanide, and azide are all commercially available and were used without additional purification. As previously reported,[9] DTPP and dioxaphospholane **2** are hydrolyzed immediately in environments not totally protected from moisture. Consequently, the detailed spectroscopic characterization of dioxaphospholane **2** as a "highly reactive precursor" was viewed as totally acceptable. Finally, mass spectral analyses were performed on a Hewlett-Packard Model 5971A GC–mass spectrometer using a GC HP1 nonpolar silica column for the analytical separations and molecular mass ($M^+$) determinations.

**4-Methyl-2,2,2-triphenyl-1,3,2λ⁵-dioxaphospholane (2).** Under anhydrous conditions, 0.22 mL of diol **1** (3.0 mmol) was added to 2.20 mL of 1.36 M DTPP in THF (3.0 mmol). The solution was stirred at ambient temperature for 15 min to complete the bis(transoxyphosphoranylation) process. The solvent and residual ethanol were removed in vacuo to afford a paste which was subsequently dissolved in 5 mL of anhydrous dichloromethane solvent for use in subsequent reactions. Dioxaphospholane **2**: $^1H$ NMR ($CDCl_3$) δ 1.2 (d, $J$ = 7.0 Hz, $CH_3$), 3.2 (m, 1 H, $J_{P-H}$ = 8.6 Hz, $^2J$ = 8.6 Hz, $^3J$ = 7.15 Hz, CH*H'O*), 3.7 (m, 1 H, $J_{P-H}$ = 17.8 Hz, $^2J$ = 8.6 Hz, $^3J$ = 5.9 Hz, C*H*H'O), and 4.05 ppm (m, 1 H, $J_{P-H}$ = 8.6 Hz, $^3J$ = 7.0 Hz, $^3J$ = 5.9 Hz, $^3J$ = 7.15 Hz, C*H*$CH_3$); $^{13}C$ NMR ($CDCl_3$) δ 19.1 (d, $^3J_{P-C}$ = 7.0 Hz, $CH_3$), 65.4 ($CH_2$), 68.1 (d, $^2J_{C-P}$ = 1.51 Hz, CH), 126–133 ($C_6H_5$) and 146 ppm (ipso carbon, $^1J_{P-C}$ = 117.5 Hz); $^{31}P$ NMR ($CDCl_3$) δ −37.2 ppm. (The $^1H$ NMR coupling constants were assigned using 2D NMR techniques.)

**Trimethyl(phenylthio)silane ($Me_3SiSPh$).**[10] Thiophenol (5.13 mL, 50.0 mmol), imidazole (128 mg, 1.87 mmol), and hexamethyldisilazane (21.1 mL, 100 mmol) were mixed and refluxed under argon for 5 h. Excess hexamethyldisilazane was removed by distillation at atmospheric pressure, and the resulting liquid was fractionally distilled under vacuum to give $Me_3SiSPh$ (86%): bp 56 °C (2 mmHg) (lit.[10] bp 72–74 °C (3 mmHg)); $^1H$ NMR ($CDCl_3$) δ 0.3 (s, 9 H, $(CH_3)_3Si$) and 7.2–7.5 ppm (m, 5 H, $C_6H_5$); $^{13}C$ NMR ($CDCl_3$) δ 0.95 [$(CH_3)_3Si$] and 126.8, 128.7, and 135.7 ppm ($C_6H_5$).

**General Procedure: Reaction of 1,3,2λ⁵-Dioxaphospholane 2 with $Me_3SiX$ (X = PhS, Cl, I, Br, CN).** The dichloromethane solution of 1,3,2λ⁵-dioxaphospholane **2** (3.0 mmol) was transferred to a 10-mm NMR tube at −78 °C (dry ice–acetone bath) under argon. The trimethylsilyl reagent, $Me_3SiX$ (3.0 mmol), was added dropwise, and the reaction mixture was allowed to stand at −78 °C overnight (18 h). The distribution of the C-2 and C-1 (silyloxy)phosphonium ions, **3** and **4**, formed by this process was determined by $^{31}P$ NMR. Specifically, for $Me_3SiCN$, the two regioisomeric oxyphosphonium ions appeared as two poorly resolved $^{31}P$ NMR resonances:

**C-2 (Silyloxy)phosphonium ion 3**: $^{31}P$ NMR ($CDCl_3$) δ 62.0 ppm; $^{13}C$ NMR ($CDCl_3$) δ −0.3 [$(CH_3)_3Si$], 17.8 ($CH_3$), 65.9 ($CH_2OH$), 83.7 (d, $J_{C-P}$ = 9.52 Hz, CHOP), and 120–140 ppm [$(C_6H_5)_3P$].

***C*-1 (Silyloxy)phosphonium ion 4**: $^{31}P$ NMR ($CDCl_3$) δ 63.5 ppm; $^{13}C$ NMR ($CDCl_3$) δ −0.3 [$(CH_3)_3Si$], 18.2 ($CH_3$), 64.6 (CHOH), 76.22 (d, $J_{C-P}$ = 9.01 Hz, $CH_2OP$), and 120–140 ppm [$(C_6H_5)_3P$].

The reaction mixture containing the regioisomeric ions **3** and **4** was then warmed to ambient temperature where the temperature was maintained until the reaction was complete (i.e., exclusive formation of TPPO was observed by $^{31}P$ NMR, δ 28.5 ppm). The yield of the different regioisomers in the crude mixture, determined after removal of $CH_2Cl_2$ (rotatory evaporator), varied from 92 to 99%.

The crude mixture was dissolved in 10 mL of MeOH, and the resulting solution was stirred for 1 h at ambient temperature in the presence of a catalytic amount of cesium fluoride (CsF). Methanol was removed by rotary evaporation, and the crude mixture was redissolved in a 3:1 hexanes–ethyl acetate solvent mixture. The insoluble TPPO was removed by "column filtration" through a thin pad (0.5 in.) of silica gel. The filtrate was condensed by rotatory evaporation and purified by "flash chromatography" using silica gel and a 3:1 hexanes–ethyl acetate solution as eluent. The isolated yields and ratios of the regioisomers are reported in Table I.

**Reaction of (*S*)-1,3,2λ⁵-Dioxaphospholane 2 with $PhSSiMe_3$.** The procedure adopted here parallels the one described for the reaction of *rac*-**2** with $PhSSiMe_3$, and it was employed without modification of the previously described experimental protocol. (*R*)-2-(Phenylthio)-1-propanol [(*R*)-**5**] was obtained, the *R* configuration was assigned, and the enantiomeric purity was established (>98% ee) using HPLC analyses of the corresponding sulfone.

**Derivatives of 1,2-Propanediol.** While all of the products are simple derivatives of 1,2-propanediol and structurally uncomplicated, all of their NMR spectroscopic data were in full agreement with their published literature data, where available. Finally, their mass spectral data were also fully consistent with their assigned structure.

**2-Iodo-1-propanol**: $^1H$ NMR ($CDCl_3$) δ 1.75 (d, 3 H, $J$ = 6.86 Hz, $CH_3$), 3.45 (dd, 1 H, $^2J$ = 11.8 Hz, $^3J$ = 6.16 Hz, CH*H'O*), 3.10 (br s, 1 H, OH), 3.60 (dd, 1 H, $^2J$ = 11.8 Hz, $^3J$ = 5.9 Hz, C*H*H'O), and 4.15 ppm (sext, 1 H, CH); $^{13}C$ NMR ($CDCl_3$) δ 22.8 ($CH_3$), 30.66 (CHI), and 69.7 ppm ($CH_2O$); MS *m/e* 186 ($M^+$), 127, and 59.

**1-Iodo-2-propanol**:[11] $^1H$ NMR ($CDCl_3$) δ 1.12 (d, 3 H, $J$ = 6.16 Hz, $CH_3$), 3.05 (dd, 1 H, $^2J$ = 10.0 Hz, $^3J$ = 5.82 Hz, CH*H'I*), 3.15 (dd, 1 H, $^2J$ = 10.0 Hz, $^3J$ = 5.04 Hz, C*H*H'I), 3.7 (m, 1 H, CHO), and 3.70 ppm (br s, 1 H, OH); $^{13}C$ NMR ($CDCl_3$) δ 16.6 ($CH_3$), 24.3 ($CH_2I$), and 67.18 ppm (CHO); MS *m/e* 186 ($M^+$), 171, 162, 127, and 59.

**2-Bromo-1-propanol**:[12] $^1H$ NMR ($CDCl_3$) δ 1.65 (d, 3 H, $J$ = 6.9 Hz, $CH_3$), 2.65 (br s, 1 H, OH), 3.62 (dd, 1 H, $^2J$ = 12.1 Hz, $^3J$ = 6.7 Hz, CH*H'O*), 3.72 (dd, 1 H, $^2J$ = 12.1 Hz, $^3J$ = 5.0 Hz, C*H*H'O), and 4.20 ppm (sext, 1 H, CHBr); $^{13}C$ NMR ($CDCl_3$) δ 21.95 ($CH_3$), 52.75 (CHBr), and 68.55 ppm ($CH_2O$); MS *m/e* 138 ($M^+$), 59, and 31.

**1-Bromo-2-propanol**:[12] $^1H$ NMR ($CDCl_3$) δ 1.25 (d, 3 H, $J$ = 6.2 Hz, $CH_3$), 2.65 (br s, 1 H, OH), 3.32 (dd, 1 H, $^2J$ = 11.0 Hz, $^3J$ = 6.7 Hz, CH*H'Br*), 3.45 (dd, 1 H, $^2J$ = 11.0 Hz, $^3J$ = 7.3 Hz, C*H*H'Br), and 4.2 ppm (m, 1 H, CHO); $^{13}C$ NMR ($CDCl_3$) δ 21.19 ($CH_3$), 40.59 ($CH_2Br$), and 67.09 ppm (CHO); MS, *m/e* 139 ($M^+$), 123, and 45.

**2-Chloro-1-propanol**:[13] $^1H$ NMR ($CDCl_3$) δ 1.40 (d, 3 H, $J$ = 6.6 Hz, $CH_3$), 3.45 (dd, 1 H, $^2J$ = 11.4 Hz, $^3J$ = 5.9 Hz, CH*H'O*), 3.50 (dd, 1 H, $^2J$ = 11.4 Hz, $^3J$ = 5.85 Hz, C*H*H'O), 3.90 ppm (sext,

(10) (a) Glass, R. S. *J. Organomet. Chem.* **1973**, *61*, 83–90. (b) Ojima, I.; Nihonyanagi, M.; Nagai, Y. *J. Organomet. Chem.* **1973**, *50*, C26–C28.

(11) Shibata, I.; Baba, A.; Iwasaki, H. *J. Org. Chem.* **1986**, *51*, 2177.

(12) Selvig, K.; Ruud-Christensen, M.; Aasen, A. J. *J. Med. Chem.* **1983**, *26*, 1514.

(13) These materials are commercially available.

1 H, CHCl), and 2.65 ppm (br s, 1 H, OH); $^{13}$C NMR ($CDCl_3$) $\delta$ 21.0 ($CH_3$), 59.37 (CHCl), and 67.63 ppm ($CH_2O$); MS $m/e$ 94 ($M^+$), 58, and 31.

**1-Chloro-2-propanol**:[13] $^1$H NMR ($CDCl_3$) $\delta$ 1.20 (d, 3 *H*, $J$ = 6.4 Hz, $CH_3$), 3.3. (dd, 1 H, $^2J$ = 10.9 Hz, $^3J$ = 5.51 Hz, CH*H'*Cl), 3.35 (dd, 1 H, $^2J$ = 10.9 Hz, $^3J$ = 5.7 Hz, C*H*H'Cl), 3.9 ppm (m, 1 H, CHO), and 2.65 ppm (br s, 1 H, OH); $^{13}$C NMR ($CDCl_3$) $\delta$ 20.27 ($CH_3$), 51.0 ($CH_2Cl$), and 67.40 ppm (CHO); MS $m/e$ 93 ($M^+$), 79, and 45.

**2-(Phenylthio)-1-propanol**: $^1$H NMR ($CDCl_3$) $\delta$ 1.20 (d, 3 H, $J$ = 6.7 Hz, $CH_3$), 2.70 (br s, 1 H, OH), 3.50 (dd, 1 H, $^2J$ = 11.2 Hz, $^3J$ = 5.9 Hz, CH*H'O*), 3.6 (dd, 1 H, $^2J$ = 11.2 Hz, $^3J$ = 6.4 Hz, C*H*H'O), 3.3 ppm (sext, 1 H, CHS), and 7.2–7.5 ppm (m, 5 H, $C_6H_5$); $^{13}$C NMR ($CDCl_3$) $\delta$ 17.6 ($CH_3$), 46.3 (CHS), 65.5 ($CH_2O$), and 126.5, 128.9, 129.9, and 132.8 ppm ($C_6H_5$); MS $m/e$ 168 ($M^+$), 137, and 110.

**1-(Phenylthio)-2-propanol**: $^1$H NMR ($CDCl_3$) $\delta$ 1.15 (d, 3 H, $J$ = 6.2 Hz, $CH_3$), 2.70 (br s, 1 H, OH), 2.85 (dd, 1 H, $^2J$ = 13.5 Hz, $^3J$ = 8.1 Hz, CH*H'S*), 3.05 (dd, 1 H, $^2J$ = 13.5 Hz, $^3J$ = 6.3 Hz, C*H*H'S), 3.85 (sext, 1 H, CHO), and 7.1–7.5 ppm (m, 5 H, $C_6H_5$); $^{13}$C NMR ($CDCl_3$) $\delta$ 21.9 ($CH_3$), 43.5 ($CH_2S$), 65.6 (CHO), and 126.7–135 ppm ($C_6H_5$); MS $m/e$ 168 ($M^+$), 126, 91, 78, and 45.

**3-Hydroxy-2-methylpropanonitrile**: $^1$H NMR ($CDCl_3$) $\delta$ 1.25 (d, 3 H, $J$ = 7.1 Hz, $CH_3$), 2.8 (sext, 1 H, CHCN), 3.4 (br s, 1 H, OH), and 3.52 ppm (d, 2 H, $J$ = 7.2 Hz, $CH_2O$); $^{13}$C NMR ($CDCl_3$) $\delta$ 14.0 ($CH_3$), 28.9 (CHCN), 63.6 ($CH_2O$), and 121.9 ppm (CN); MS $m/e$ 84 ($M^+$), 55, 54, and 31.

**3-Hydroxybutanonitrile**: $^1$H NMR ($CDCl_3$) $\delta$ 1.28 (d, 3 H, $J$ = 6.25 Hz, $CH_3$), 2.41 (dd, 1 H, $^2J$ = 16.9 Hz, $^3J$ = 5.95 Hz, CH*H'CN*), 2.52 (dd, 1 H, $^2J$ = 16.9 Hz, $^3J$ = 5.31 Hz, C*H*H'CN), 3.4 (br s, 1 H, OH), and 4.1 ppm (m, 1 H, CHO); $^{13}$C NMR ($CDCl_3$) $\delta$ 22.5 ($CH_3$), 27.3 ($CH_2CN$), 63.8 (CHO), and 121.9 ppm (CN); MS $m/e$ 84 ($M^+$), 45, and 42.

**2-Azido-1-propanol**: $^1$H NMR ($CDCl_3$) $\delta$ 1.2 (d, 3 H, $J$ = 6.11 Hz, $CH_3$), 2.0 (br s, 1 H, OH), 3.45 (dd, 1 H, $^2J$ = 11.8 Hz, $^3J$ = 7.9 Hz, CH*H'O*), and 3.55–3.7 ppm (m, 2 H, C*H*H'O and $CHN_3$); $^{13}$C NMR ($CDCl_3$) $\delta$ 14.4 ($CH_3$), 58.38 ($CHN_3$), and 65.4 ppm ($CH_2O$); MS $m/e$ 101 ($M^+$), 42, and 31.

**1-Azido-2-propanol**: $^1$H NMR ($CDCl_3$) $\delta$ 1.2 (d, 3 H, $J$ = 6.34 Hz, $CH_3$), 3.15 (dd, 1 H, $^2J$ = 12.4 Hz, $^3J$ = 7.1 Hz, CH*H'*$N_3$), 3.15 (dd, 1 H, $^2J$ = 12.4 Hz, $^3J$ = 3.89 Hz, C*H*H'$N_3$), 3.9 (m, 1 H, CHO), and 5.2 ppm (br s, 1 H, OH); $^{13}$C NMR ($CDCl_3$) $\delta$ 21.2 ($CH_3$), 58.0 ($CH_2N_3$), and 66.1 ppm (CHO); MS $m/e$ 101 ($M^+$), 45, and 29.

**Reactions of Propylene Oxide with $Me_3SiX$ (X = PhS, I, Br, Cl, CN, and $N_3$).[14] General Procedure.** To a solution of propylene oxide (3.0 mmol) in $CH_2Cl_2$ was added the $Me_3SiX$ reagent (3.1 mmol) at room temperature. In some cases the addition of a catalyst or an initiator was necessary (Table II). The mixture was stirred until the reaction was complete as determined by $^{31}$P NMR spectroscopy. The crude mixture was dissolved in 10 mL of MeOH and stirred for 1 h at ambient temperature in the presence of 1.5 mmol of methanolic CsF. Methanol was removed by rotary evaporation, and the crude mixture was purified by "flash" chromatography using silica gel and a 3:1 hexanes–ethyl acetate solution as eluent. The isolated yields ranged from 65 to 92%, and ratios of the different regioisomers were determined by NMR spectroscopy (Table II).

**Reaction of (*S*)-1,3,2λ$^5$-Dioxaphospholane 2 with *p*-TsOH.** Under anhydrous conditions, 0.22 mL of (*S*)-(+)-1,2-propanediol (3.0 mmol) was added to 2.20 mL of 1.36 M DTPP in tetrahydrofuran solvent (3.0 mmol). The solution was stirred at ambient temperature for 15 min. The solvent and residual ethanol were removed in vacuo to afford a paste which was dissolved in 5 mL of anhydrous THF. Anhydrous *p*-TsOH (1.87 mL of a 1.66 M THF solution; 3.1 mmol) was added at ambient temperature and stirred for 18 h to give (*R*)-2-(((4-methylphenyl)sulfonyl)-oxy)-1-propanol, (*R*)-7.[6]

Tosylate 7 was isolated by removal of the THF solvent (rotatory evaporator) to yield an oily residue (95% of the crude mixture as determined by $^1$H NMR). Tosylate (*R*)-7 was purified by flash chromatography using silica gel and a 3:1 hexanes–ethyl acetate eluent to afford homogeneous (*R*)-7 (TLC) as a syrupy residue (60%): $^1$H NMR ($CDCl_3$) $\delta$ 1.2 (d, 3 H, $J$ = 6.6 Hz, $CH_3$), 2.1 (br s, 1 H, OH), 2.45 (s, 3 H, $H_3C$-$C_6H_4$), 3.6 (d, 2 H, $J$ = 6.0 Hz, $CH_2$), 4.67 (m, 1 H, $J$ = 6.0 Hz, CH), and 7.3–7.9 ppm (m, 4 H, $C_6H_4$); $^{13}$C NMR ($CDCl_3$) $\delta$ 16.9 ($CH_3$), 21.6 ($H_3C$-$C_6H_4$), 65.5 ($CH_2$), 80.0 (CH), 127.7, 129.8, 134.5, and 145.3 ppm ($C_6H_4$); MS $m/e$ 230 ($M^+$), 199, 155, and 91. A $^1$H NMR study using the chiral shift reagent, Eu(hfc)$_3$, indicated a 97% ee. The *R* configuration was assigned on the basis of the expected stereospecificity attending the thiophenate displacement of tosylate to afford (*S*)-2-(phenylthio)-1-propanol, (*S*)-5.

**Reaction of (*R*)-2-(((4-Methylphenyl)sulfonyl)oxy)-1-propanol [(*R*)-7] with Lithium Benzenethiolate.** (*R*)-2-(((4-Methylphenyl)sulfonyl)oxy)-1-propanol (368 mg, 1.60 mmol) was dissolved in THF solvent and reacted with 0.18 mL (2.0 mmol) of 3,4-dihydro-2*H*-pyran in the presence of a catalytic amount of pyridinium *p*-toluenesulfonate (PPTS) to afford the tetrahydropyranyl (THP) ether of (*R*)-7. A solution of PhSLi was prepared by adding 0.31 mL (3.0 mmol) of PhSH and 1.2 mL of *n*-BuLi (3.0 mmol, 2.5 M in hexanes) in anhydrous THF solvent (at −78 °C under argon). The PhSLi solution (3.0 mmol) was added at −78 °C (dry ice–acetone bath) to the reaction mixture containing the THP ether of (*R*)-7 at −78 °C. The mixture was refluxed overnight. The reaction mixture was quenched with a saturated $NH_4Cl$ solution. The aqueous layer was extracted with dichloromethane (2 × 20 mL), and the organic layers were combined and dried ($K_2CO_3$).

After filtration and removal of the solvents (rotatory evaporator), the crude mixture was dissolved in 20 mL of methanol in the presence of PPTS (1.5 mmol). The crude mixture was purified by flash chromatography using silica gel and 3:1 hexanes–ethyl acetate as eluent to afford homogeneous (*S*)-2-(phenylthio)-1-propanol (60%). The *S* configurational assignment for **5** was established by HPLC analysis after its oxidation to the corresponding sulfone and comparison with HPLC retention times.

Hydrogen peroxide (1.5 equiv) as a 30% aqueous solution and a catalytic amount of AcOH were added to 1 equiv of (*S*)-**5** which was dissolved in THF, and the resulting solution was refluxed for 3 h. The aqueous layer was extracted with dichloromethane (4 × 20 mL), and the combined organic layers were dried ($K_2CO_3$). Removal of the solvent (rotatory evaporator) gave a mixture of (*S*)-2-(phenylsulfonyl)-1-propanol (60%) and the diastereomeric 2(*S*)-(phenylsulfinyl)-1-propanols (40%).

**Acknowledgment** is made to the National Science Foundation and Rhône-Poulenc, Agrochimie, for support of this research as well as for a fellowship from Rhône-Poulenc to IMP. We are also grateful to Dr. Daniel Sternbach of the Medicinal Chemistry Section of Glaxo, Inc., for his valuable suggestions and to ATOCHEM of North America, Elf Aquitaine, for a generous supply of triphenylphosphine.

**Supplementary Material Available:** $^1$H and/or $^{13}$C NMR spectra for all relevant compounds (12 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

(14) (a) Guidon, Y.; Young, R. N.; Frenette, R. *Synth. Commun.* **1981**, *11*, 391. (b) Andrews, G. C.; Crawford, T. C.; Contillo, L. G., Jr. *Tetrahedron Lett.* **1981**, *22*, 3808. (c) Kricheldorf, H. R.; Morber, G.; Regel, W. *Synthesis* **1981**, 383. (d) Gassman, P. G.; Guggenheim, T. L. *J. Am. Chem. Soc.* **1982**, *104*, 5850. (e) Blandy, C.; Choukroum, R.; Gervais, D. *Tetrahedron Lett.* **1983**, *24*, 4189.