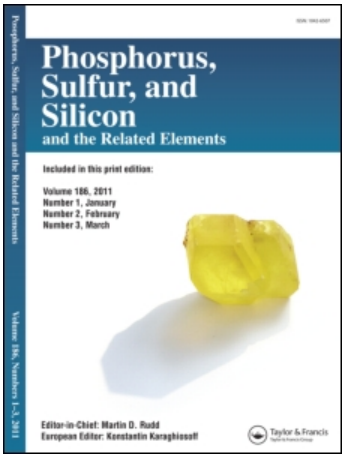

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SYNTHESIS AND STEREOCHEMISTRY OF 1-OXA-6-HETERASPIRO[2.5]OCTANES. SINGLE-CRYSTAL ANALYSIS OF 6-PHENYL-1-OXA-6-PHOSPHASPIRO[2.5]OCTANE 6-SULFIDE

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SYNTHESIS AND STEREOCHEMISTRY OF 1-OXA-6-HETERASPIRO[2.5]OCTANES. SINGLE-CRYSTAL ANALYSIS OF 6-PHENYL-1-OXA-6-PHOSPHASPIRO[2.5]OCTANE 6-SULFIDE

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The synthesis of several 1-oxa-6-heteraspiro[2.5]octanes is reported herein for the first time. Stereochemical analysis via NMR studies and a single crystal X-ray diffraction analysis of 6-phenyl-1-oxa-6-phosphaspiro[2.5]octane 6-sulfide have been completed and provide the basis for correlations of structures for other members of the families yet unknown. Epoxidation of *cis*-2,6-diphenyl-4-thianone with dimethyloxosulfonium methylide in DMSO led, surprisingly, to a tertiary alcohol, presumably via ring opening of the expected intermediate epoxide. This is the first example of this type of ring opening in the presence of this base but the reaction time was longer than that normally employed in this process.

Since the family members of the parent spiro[2.5]octanes are rare, an X-ray diffraction analysis was performed on 6-phenyl-1-oxa-6-phosphaspiro[2.5]octane 6-sulfide. This analysis revealed a space group of $Pna2_1$ with cell dimensions of: a = 13.056(3) Å, b = 14.268(3) Å, and c = 6.1522(11) Å. The phosphorinane ring assumes a slightly flattened chair conformation with the phenyl-P bond being equatorial and the P=S bond being axial. The plane of the epoxide is virtually coincident with a pseudo-mirror plane through P(6), C(3), C(9) and S(15). The phenyl group is rotated out of this plane by 28.2°. Although the P—C distances (ring carbons) are 1.813(3) Å and 1.819(3) Å, respectively, and appear to be about normal, the P-phenyl bond of 1.813(3) Å is longer than in a few model systems. The C(3)—O(1) bond in the epoxide is axial or rather pseudo axial. Ring deformations are consistent with a few model epoxides the structures of which have been identified.

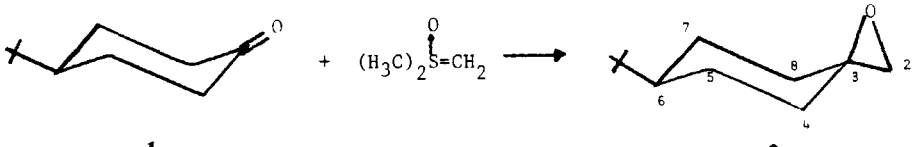
INTRODUCTION

Several natural products containing the oxirane group are known to be biologically active and even the simple carbocyclic 1-oxaspiro[2.5]octane has shown a moderate activity.[1] Among the most active cytostatic agents, a few are known to possess 3-hetera-1-oxaspiro[2.5]octane systems, and the heteraspiro epoxide variety is believed to be the active center in the molecules.[2] It is conceivable that a structure-activity relationship may exist involving the conformation of the oxirane group. However, sufficient data are not available to test this hypothesis at this time. Studies in the heterocyclic oxiranes systems are not as extensive as in carbocyclic systems.[3] In view of this situation, we have prepared a number of 1-oxa-6-heteraspiro[2.5]oc-

tanes from the corresponding 1-hetera-4-cyclohexanones. Moreover, these oxiranes also served as precursors in the synthesis of several heretofore unknown 3-methylene-1-oxa-8-heteraspiro[4.5]decan-2-ones which are otherwise difficult to obtain.[4] Herein we report only the synthesis, stereochemistry and spectral studies of the oxiranes. The first single crystal X-ray diffraction analysis of a member of this family is also recorded.

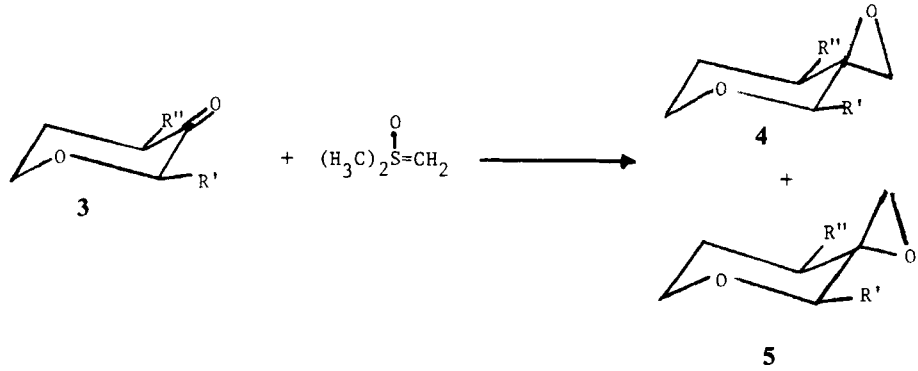
RESULTS AND DISCUSSION

The synthesis and stereochemistry of several substituted 1-oxaspiro[2.5]octanes have been studied by Corey and Chaykovsky.[5] From a reaction of dimethyloxosulfonium methylide (prepared by a reaction of trimethyloxosulfonium iodide and sodium hydride) with 4-*tert*-butylcyclohexanone (**1**), they could isolate *cis*-6-*tert*-butyl-1-oxaspiro[2.5]octane (**2**) as a single product (90%).[5] The formation of oxirane **2** was



1 **2**

rationalized as the result of a more favorable equatorial approach of the ylide.[5] However, the same ylide on reaction with substituted 3-oxanones **3** gave epimeric oxiranes **4** and **5** in approximately equal amounts.[1] In our hands, heterocyclic ketones **6a–k**, when treated with dimethyloxosulfonium methylide, gave oxiranes



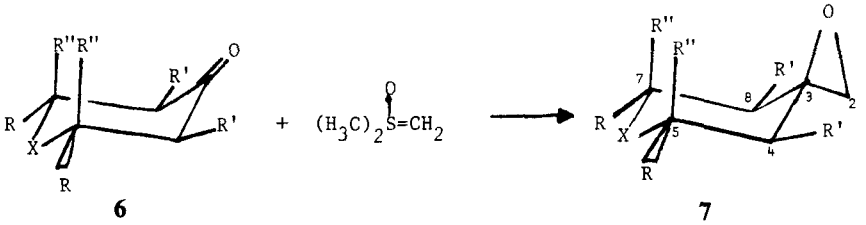
3 **4** **5**

a. R' = R" = CH_3

b. R' = H; R" = CH_3

c. R' = CH_3; R" = H

7a–k in modest yields (≃ 25–30%). However, various modifications of the reaction conditions did give improved yields (see Experimental). The reactions of the dimethyloxosulfonium methylide with ketones **6** was generally conducted in the DMSO.



6 7

a. X = O; R = R' = R" = H

b. X = S; R = R' = R" = H

c. X = NCH_3; R = R' = R" = H

d. X = $NCH_2C_6H_5$; R = R' = R" = H

e. X = PC_6H_5; R = R' = R" = H

f. X = $P(S)C_6H_5$; R = R' = R" = H

g. X = O; R = C_6H_5; R' = R" = H

h. X = S; R = C_6H_5; R' = R" = H

i. X = NH; R = C_6H_5; R' = CH_3; R" = H

j. X = NH; R = R" = CH_3; R' = H

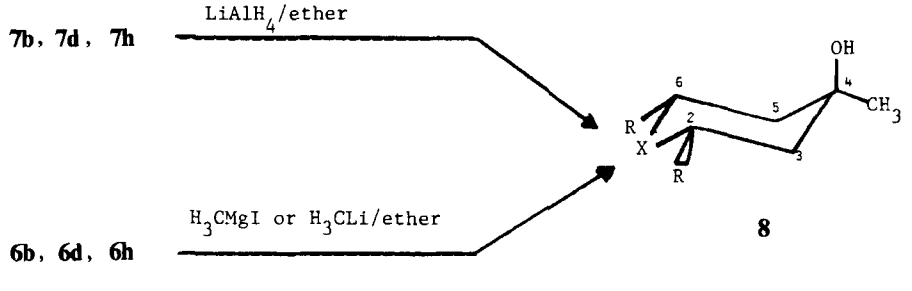
k. X = $P(S)C_6H_5$; R = R" = CH_3; R' = H

l. X = $P^+(C_6H_5)(CH_2C_6H_5),Br^-$; R = R' = R" = H

m. X = $P^+(C_6H_5)(CH_2C_6H_5),PF_6^-$; R = R' = R" = H

Oxiranes **7a**, **7c**, and **7j** were found to be extremely soluble in DMSO and, hence in these cases, the reactions were performed in THF while the ylide was produced by treating trimethyloxosulfonium chloride with NaH in THF.

The stereochemistry of the spiro epoxides has commonly been determined via reduction with $LiAlH_4$ to the corresponding tertiary alcohols which were either known compounds or possessed a configuration which could be assigned from dehydration studies.[1,5-7] Whenever the epimeric epoxides were available, the ^1H NMR spectra have been used to differentiate them.[8] In our work, oxiranes **7b**, **7d** and **7h** were reduced by $LiAlH_4$ in ether to give the corresponding tertiary alcohols **8a**, **8b**, and **8c**. Addition of CH_3MgI or CH_3Li to ketones **6b**, **6d** and **6h** also gave the tertiary alcohols **8a–c**, respectively. Alcohol **8a** is presumably a conformationally mobile system. The major isomers which resulted from addition of CH_3MgI or



8

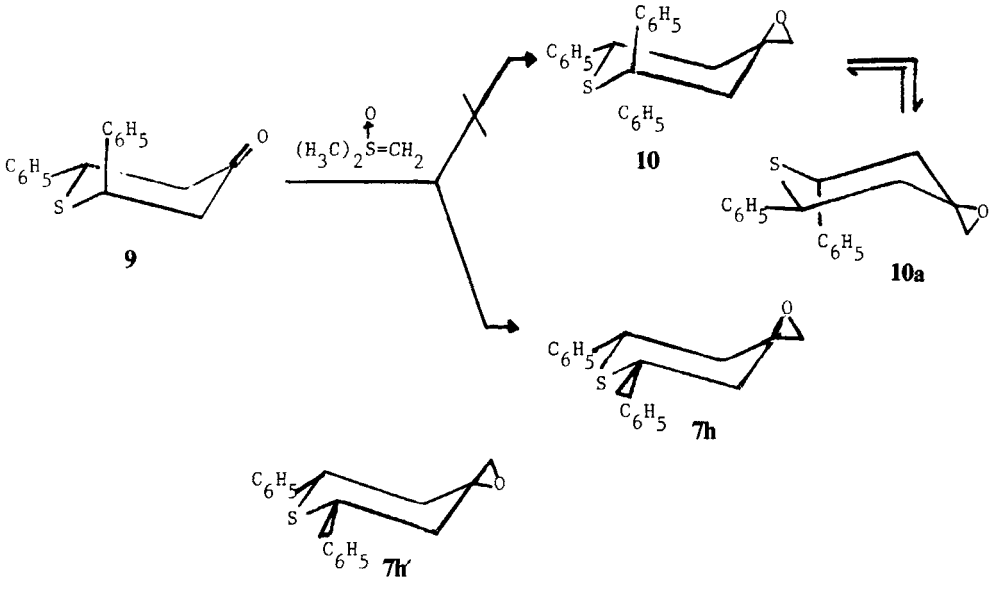
a. X = S; R = H

b. X = $NCH_2C_6H_5$; R = H

c. X = S; R = C_6H_5

CH_3Li to the ketones **6d** and **6h** were **8b**[9,10] and **8c**[10] in which the C—O bonds were axial. This observation is in agreement with the more favorable equatorial approach of the Grignard reagent.[11,12] Tertiary alcohols **8a–c** prepared by this method were identical with the alcohols obtained by the reduction of the oxiranes **7b**, **7d** and **7h**, respectively. Thus it was tentatively concluded that the C(3)—O bonds in the oxiranes **7d** and **7h** were axial. Although this method of assigning the stereochemistry appeared to be correct, it was felt that X-ray analysis of a single crystal of one member of this family would permit possible correlations with other related systems in an unequivocal fashion. Thus, we have obtained the X-ray diffraction data on a single crystal of **7f**, the data being given later in this paper.

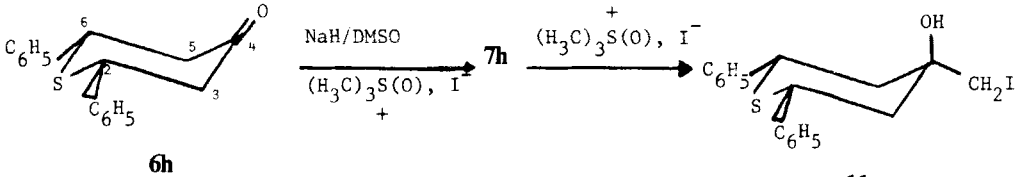
The reaction of dimethyloxosulfonium methylide with *r*-2,*trans*-6-diphenyl-4-thianone (**9**) was quite interesting. Instead of the expected oxirane **10** (or **10a**), there was isolated only the oxirane **7h**. This may be due to the isomerization of the less



stable isomer **9** [axial-equatorial arrangement of the phenyl groups] to the more stable isomer **6h** [diequatorial arrangement of the C—C_6H_5 bands] during the reaction. The probability of the isomerization of the axial phenyl group to an equatorial position in the thianone family has been recognized.[10b,13] It is presumed that the thianone **9** isomerized first to the thianone **6h** before it could react with the ylide. On the other hand, if the oxirane **10** (or **10a**) formed first and then isomerized, there might be two products, namely **7h** and its C(3) epimer **7h'**, but this was *not* observed.

Modification of the conditions (heating and longer reaction time) involving reaction of the oxosulfonium ylide with the thianone **6h** proved to be novel and gave the tertiary alcohol **11**. Formation of the alcohol is probably due to the attack of the

excess oxosulfonium iodide during the increased reaction time on the oxirane **7h** formed. Since the C—O bond was axial in **7h**, the C(4)—OH bond is most probably

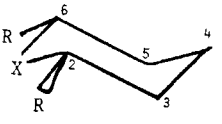


6h **11**

axial in the alcohol **11**. *This is the first report of the formation of an alcohol during the reaction of the dimethyl oxosulfonium methylide with heterocyclic ketones.*

The oxiranes **7a–m** were characterized by IR, ^{1}H NMR and ^{13}C NMR spectra (see Tables I and II). Peaks of medium intensity were observed around 1250, 950 and 850 cm^{-1} in the IR spectra, all bands being characteristic of an oxirane group.[1,14] The methylene group of the oxirane appeared as a singlet in the ^{1}H NMR spectra in the region δ 2.50–2.80.

In analyzing the ^{13}C NMR spectra, it was useful to compare the chemical shifts of carbons in the oxiranes **7a–d**, **7f** and **7h** with the corresponding shifts in the heteracyclohexanes **12a–f**[15–17] (Tables II and III). An upfield shift of 1–3 ppm was found for C(5,7) in the oxiranes **7a–d**, **7f** and **7h** in comparison with the correspond-



12

a. X = O; R = H; b. X = S; R = H; c. X = NCH_3; R = H

d. X = $NCH_2C_6H_5$; R = H; e. X = $P(S)C_6H_5$; R = H; f. X = S; R = C_6H_5

ing carbons C(2,6) in the respective counterparts of **12**. This is probably due to the γ-effect of the C—O or C—CH_2 bond of the oxirane group on C(5,7) in members of **7**.[16b] Similar effects have been observed in the case of several 1-hetera-4-cyclohexanols[18] and also in epimeric 8-*tert*-butyl-3-methylene-1-oxospiro[4.5]decan-2-ones.[4] The introduction of the oxirane group in **12** also causes significant deshielding of C(3,5) (~ 6–7 ppm) and C(4) (~ 30–33 ppm) compared to the corresponding carbons in members of **12**.

The heterocyclic spiro systems are the first of this type to be recorded with phosphorus in the six-membered ring. In view of the previous work with the oxanones,[1] it appears that the position of the heteroatom in the six-membered ring may influence the direction of epoxidation. An X-ray diffraction analysis of **7f** has been completed in order that correlations of structure may be possible with many examples which remain to be synthesized.

TABLE I

IR and ^{1}H NMR data for oxiranes

Compd.	IR,[a] cm^{-1} (Oxiranes)	^{1}H NMR Chemical Shifts[b] δ, ppm
7a[c]	1265, 950, 860	1.36–2.02 [m, 4 H, H(4), H(8)], 2.64 [s, 2 H, H(2)], 3.60–3.94 [m, 4 H, H(5), H(7)]
7b	1235, 920, 900	1.50–2.20 [m, 4 H, H(4), H(8)], 2.40–3.10, [m, 4 H, H(5), H(7)], 2.59 [s, 2 H, H(2)]
7c[c]	1260, 955, 920 900, 845	1.38–2.02 [m, 4 H, H(4), H(8)], 2.32 [s, 3 H, NCH_3], 2.44–2.60 [m, 4 H, H(5), H(7)], 2.61 [s, 2 H, H(2)]
7d[c]	1255, 920, 845	1.34–2.00 [m, 4 H, H(4), H(8)], 2.46–2.56 [m, 4 H, H(5), H(7)], 2.57 [s, 2 H, H(2)], 3.51 [s, 2 H, $CH_2C_6H_5$], 7.12–7.40 [m, 5 H, ArH]
7f[d]	1270, 935, 890	1.14–2.24 [m, 4 H, H(4), H(8)], 2.40–3.20 [m, 4 H, H(5), H(7)], 2.76 [s, 2 H, H(2)], 7.26–7.64 and 7.80–8.14 [m, 5 H, ArH]
7g	1250, 950, 905	1.40–1.68 [m, 2 H, $H(4_a)$, $H(8_a)$], 2.10–2.42 [m, 2 H, $H(4_e)$, $H(8_e)$], 2.78 [s, 2 H, H(2)]; 4.84–5.06 [dd, 2 H, H(5), H(7), J = 12.0 and 2.0 Hz], 7.14–7.56 [m, 10 H, ArH]
7h	1260, 1255, 940 890	1.64–1.88 [dd, 2 H, $H(4_a)$, $H(8_a)$, J = 14.0 and 3.0 Hz], 2.44–2.71 [m, 2 H, $H(4_e)$, $H(8_e)$], 2.72 [s, 2 H, H(2)], 4.34–4.54 [dd, 2 H, H(5), H(7), J = 12.0 and 2.0 Hz], 7.04–7.58 [m, 10 H, ArH]
7i	1230, 940, 900	0.55 [d, 6 H, $2CH_3$, J = 7.0 Hz], 1.78 [s, 1 H, NH], 2.16–2.50 [m, 2 H, H(4), H(8)], 2.80 [s, 2 H, H(2)], 3.78 [d, 2 H, H(5), H(7), J = 10.0 Hz], 7.14–7.50 [m, 10 H, ArH]
7j[c]	1240, 950, 910 840	1.22 [d, 12 H, 4 CH_3, J = 5.0 Hz], 1.46 [s, 5 H, H(4), H(8), NH], 2.64 [s, 2 H, H(2)]
7k[e]	1250, 920, 830	0.93 [d, 6 H, $2CH_{3a}$, $^3J_{PH}$ = 16.0 Hz], 1.60 [d, 6 H, $2CH_{3e}$, $^3J_{PH}$ = 16.0 Hz], 1.74–2.00 [m, 2 H, $H(4_a)$, $H(8_a)$], 2.48–2.84 [m, 2 H, $H(4_e)$, $H(8_e)$], 2.60 [s, 2 H, H(2)], 7.34–7.62 and 8.04–8.40 [m, 5 H, ArH]
7l[f]	938, 870, 860	1.60–2.50 [m, 4 H, H(4), H(8)], 2.82 [s, 2 H, H(2)], 3.40–4.00 [m, 4 H, H(5), H(7)], 4.94 [d, 2 H, $CH_2C_6H_5$ $^2J_{PH}$ = 16.0 Hz], 7.00–8.00 [m, 10 H, ArH]

[a] The spectra were obtained on samples (1.5 mg) with KBr (100 mg) pellets unless otherwise noted.

[b] Spectra were obtained in $DCCl_3$ solution with TMS as an internal standard; peak positions quoted in the case of doublets are measured from the approximate center, and relative peak areas are given as whole numbers.

[c] IR spectra recorded as a thin film.

[d] ^{31}P NMR (in $DCCl_3$, ppm from 85% H_3PO_4), 32.92.

[e] ^{31}P NMR (in $DCCl_3$, ppm from 85% H_3PO_4), 65.55. ^{31}P decoupled ^{1}H NMR ($DCCl_3$; δ) 0.96 [s, 6 H, $2CH_{3a}$], 1.62 [s, 6 H, $2CH_{3e}$], 1.76 [d, 2 H, $H(4_a)$, $H(8_a)$, J = 15 Hz], 2.62 [s, 2 H, H(2)], 2.66 [d, 2 H, H(4), H(8), J = 15.0 Hz].

[f] ^{31}P NMR signal (in $DCCl_3$ and in ppm from 85% H_3PO_4), 17.99.

Single Crystal Analysis of ***7f***

A side view of a single molecule of 6-phenyl-1-oxa-6-phosphaspiro[2.5]octane 6-sulfide (**7f**) is shown in Figure 1. The numbering scheme and the interatomic bond distances are shown in Figure 2. Figure 3 shows the bond angles. Crystal data and intensity data are in Table IV. The phosphorinane ring assumes a slightly flattened

TABLE II

^{13}C NMR data for oxiranes[a]

Compd.	C(2)	C(3)	C(4) C(8)	C(5) C(7)	Other
7a	52.71	55.45	33.21	65.60	
7b	54.23	56.96	35.19	27.34	
7c	52.44[d]	55.71	32.37	53.41	$N\underline{C}H_3$, 45.44
7d	52.47[d]	56.24	32.36	51.16	$N\underline{C}H_2C_6H_5$, 62.04; Ar, 137.76, 127.96, 127.29, 126.06
7f[b]	55.36	56.99	28.50	28.98	$\underline{Ar}$, C(ipso), 131.64 (79.41); C(α), 130.45 (10.31);
	(0.00)	(7.34)	(5.17)	(51.52)	C(β), 128.60 (11.95); C(γ), 131.74 (3.43)
7g	52.94	56.62	40.71	77.28	Ar, 141.88, 128.08, 127.21, 125.46
7h	54.65	57.92	41.38	46.22	Ar, 140.48, 128.42, 127.40, 127.23
7i	46.02	61.46	41.03	65.83	$\underline{C}H_3$, 10.04; Ar, 143.25, 127.81, 127.67, 127.00
7j	52.82	56.00	44.74	51.62	$\underline{C}H_{3e}$, 32.31; $\underline{C}H_{3a}$, 31.49
7k[b]	50.22	54.73	44.70	36.10	$\underline{C}H_{3e}$, 27.44 ($\overline{2}.04$); $\underline{C}H_{3a}$, 26.49 (0.00).
	(0.00)	(8.09)	(0.00)	(42.51)	$\underline{Ar}$, C(ipso), 129.29 ($\overline{81}.55$); C(α), 133.05 (8.10); C(β), 127.93 (10.52); C(γ), 130.97 (2.89)
7l[b,c]	55.39	55.90	28.19	29.58	$\underline{C}H_2C_6H_5$, 16.83 (47.97)
	(0.00)	(6.86)	(6.02)	(43.44)	

[a]Spectra recorded in $DCCl_3$ and data given in ppm from Me_4Si.
[b]J_{PC} in parentheses are in Hertz.
[c]The signals for Ar—$\underline{C}$ were complex and could not be assigned unequivocally.
[d]See Ref. 44.

TABLE III

^{13}C NMR chemical shifts for 1-heteracyclohexanes[a]

Compd.	X	R	C(2) C(6)	C(3) C(5)	C(4)
12a[15]	O	H	68.7	26.9	23.8
12b[15]	S	H	29.1	27.9	26.6
12c[15]	NCH_3	H	57.4	26.7	22.7
12d[15]	$NCH_2C_6H_5$	H	54.6	26.0	24.5
12e[16]	$P(S)C_6H_5$	H	31.9	21.8	26.6
			(60)	(6)	(8)
12f[17]	S	C_6H_5	49.07	34.17	27.51

[a]Recorded in $DCCl_3$.

chair conformation, with the phenyl group at P(6) in the equatorial position, and the S atom in an axial position. The oxygen atom of the epoxide group takes up the axial position at atom C(3) (Figure 1). Excluding the phenyl group, the molecule possesses a pseudo-mirror plane which passes through the atoms P(6), C(3), C(9) and S(15). The plane of the epoxide ring is virtually coincident with the pseudo-mirror plane, while the phenyl ring is rotated out of this plane by 28.2°. The corresponding angle in some related structures is: 17.8° (molecule A) and 77.1° (molecule B) in 1-phenyl-4-phosphorinanone 1-oxide (**13**) [two molecules in the unit cell],[19] 20.7° in 1-phenyl-4-phosphorinanone 1-sulfide (**6f**),[19] and 20.1° in *trans*-4-*tert*-butyl-1-phenylphosphorinane 1-oxide (**14**).[20] The torsion angles of the heterocyclic ring in **7f** are

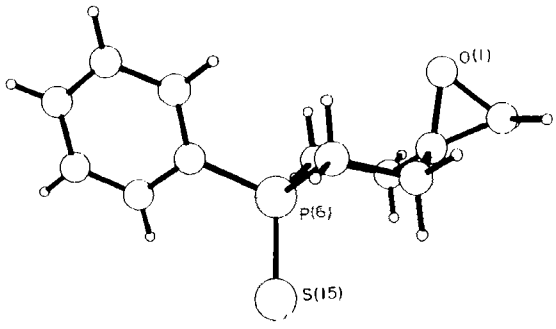
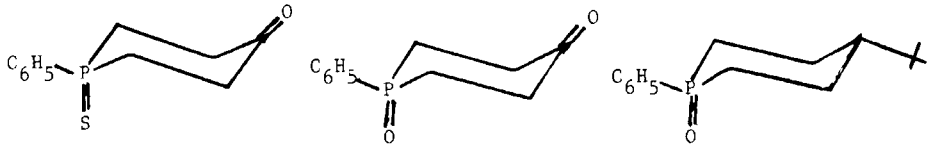


FIGURE 1 A side view of the molecule for **7f**.

given in Table V along with those observed in three related structures **6f**, **13**, and **14**. In all four molecules, the phosphorinane ring is in a chair conformation, but there are some noticeable differences in their torsion angles. The magnitudes of most of



6f **13** **14**

the torsion angles in **14** and **7f** are larger than those in **6f** and **13**. These differences are primarily due to different hybridization of atom C(3), [(sp^2) in **6f** and **13**, (sp^3) in

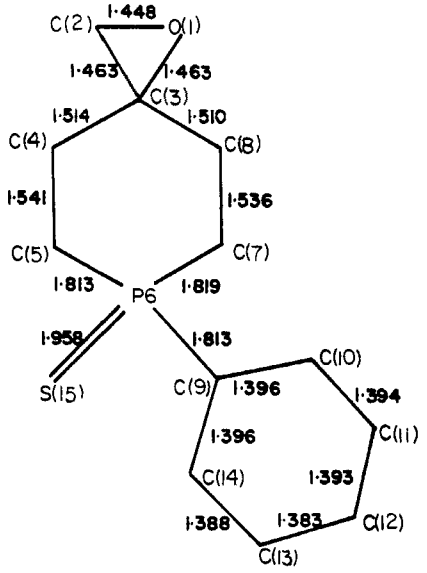


FIGURE 2 Atom numberings Scheme and bond lengths for **7f**. Standard deviations are P—S: 0.001 Å, P—C: 0.003 Å, C—C, C—O: 0.004–0.005 Å.

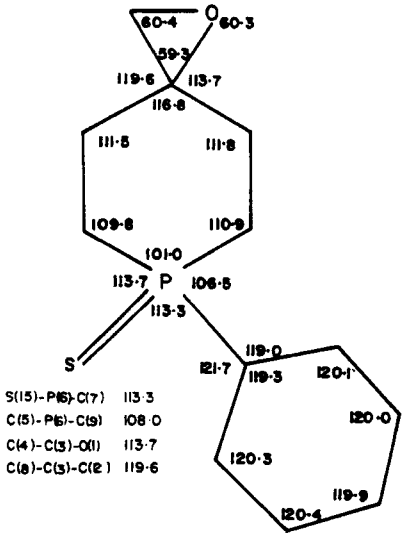


FIGURE 3 Bond angles for **7f**. Standard deviations: at P: 0.1°; others: 0.2–0.3°.

14 and **7f**]. The torsion angles in **7f** are systematically smaller than in **14**. Such changes in the conformation of the phosphorinane ring could be the result of structural differences in the two molecules, namely the axial P=S bond at P(6) and axial C—O bond at C(3) in **7f** compared to an axial P=O at P(6) and an axial C—H bond at C(4) in molecule **14**. In contrast, the rather significant differences in torsion angles between molecule A and molecule B in **13** indicated that the relative orientation of the phenyl ring played a major role in phosphorinane ring conforma-

TABLE IV

Crystal data and intensity data collection parameters for **7f**

Formula	$C_{12}H_{15}OSP$
F.W.	238.3
Space group	$Pna2_1$
Unit Cell Dimensions	a = 13.056(3) Å
(at −135°C)	b = 14.268(3)
	c = 6.1522(11)
	V = 1146.1
D_c (at 20°C)	1.354 gm cm^{-3} (assuming cell volume 2% larger at room temperature)
D_m (at 20°C)	1.341 gm cm^{-3}
Z	4
Intensity Data	
Radiation	CuK$\bar{\alpha}$ (Ni-filtered)
Scan mode	θ–2θ
θ_{max}	75°
Scan angle	$(0.80 + 0.14 \tan\theta)°$
Aperture	$(3.0 + 0.86 \tan\theta)$mm
Maximum scan time	90 seconds
μ(Cu-radiation)	34.8 cm^{-1}

TABLE V

Torsion angles in the heterocyclic ring of **7f** and related systems

	13	**14**	**15**	**7f**
P(6)—C(5)—C(4)—C(3)	56.7, 59.8	59.2	61.9	60.0
C(5)—C(4)—C(3)—C(8)	−56.8, −55.7	−55.1	−62.4	−61.2
C(4)—C(3)—C(8)—C(7)	56.9, 51.6	53.3	63.6	59.6
C(3)—C(8)—C(7)—P(6)	−57.4, −51.9	−56.8	−63.8	−57.4
C(8)—C(7)—P(6)—C(5)	54.9, 53.0	57.2	55.3	54.5
C(7)—P(6)—C(5)—C(4)	−54.2, −56.6	−57.9	−54.7	−55.5
Dihedral angle between the phenyl ring and the heterocyclic ring	17.8, 77.1[a]	20.7[b]	20.1[c]	28.2[d]

[a]1-phenyl-4-phosphorinanone-1-oxide (**13**).[19]
[b]1-phenyl-4-phosphorinanone-1-sulfide (**6f**).[19]
[c]*trans*-4-*tert*-butyl-1-phenylphosphorinane (**14**).[20]
[d]Present structure **7f**.

tion. In comparison, the dihedral angle between the phenyl ring and the heterocyclic ring is 29.2° in **7f**, and it is 20.1° in **14**.

The two P—C(sp^3) bond distances in **7f** of 1.813(3) Å and 1.819(3) Å are similar to those in **6f** [1.818(4) and 1.814(3) Å], but they are longer than those in **13** [1.800(3) and 1.794(3), 1.808(3) and 1.802(3) Å] and in molecule **14** [1.791(2) and 1.795(2) Å]. The P—C(phenyl) distance of 1.813(3) Å in **7f** is longer than observed in the related compounds: 1.799(2), 1.800(2) Å in **6f**, 1.803(3) in **13** and 1.805(2) Å in **14**. The P=S distance in **7f** of 1.958(1) Å is also longer than those observed in other related structures, namely, 1.949(1) Å in **6f**, 1.936(5) and 1.947(5) Å in tri-*m*-tolylphosphine 1-sulfide[21] and tri-*o*-tolylphosphine 1-sulfide,[22] respectively. However, an even longer P=S distance of 1.964(4) Å (average value) has been reported in the case of a 4-phosphorinanol 1-sulfides.[23]

The endocyclic bond angle at P in **7f** is 1.2° larger than that in **6f**, whereas it is about 0.5° smaller than the one in the corresponding oxide **13**. The endocyclic angle at C(3) (116.8°) differs significantly from the tetrahedral value and this is due to the attached epoxide ring in **7f**.

The dimensions of the spiro epoxide ring in **7f** are: C(2)—O(1) = 1.448(3), C(3)—O(1) = 1.463(4), C(2)—C(3) = 1.463(4) Å, C(2)—O(1)—C(3) = 60.3(2)°, C(2)—C(3)—O(1) = 59.3(2)°, and C(3)—C(2)—O(1) = 60.4(2)°, area = 0.920 $Å^2$. The deviations from the symmetric geometry of the oxirane ring[24] are consistent with the surveys of epoxide structural results[25,26] where it has been shown that the epoxide ring, if deformed in bond distances and angles, maintains a constant area (0.910–0.920 $Å^2$). Such geometrical changes are more distinct in most spiro epoxides[27-29] than in fused epoxide rings covered in the surveys cited above. However, in the diepoxide of cyclohexane,[30] which contains a spiro epoxide with an equatorial C—O bond and a fused epoxide group with an axial oxygen, it is seen that the spiro epoxide is less distorted than the fused one. The results indicate that the deformation in the epoxide geometry is determined by the relative position of the

TABLE VI

Positional parameters ($\times 10^4$) for non-hydrogen atoms in **7f**. Standard deviations for last digits are in parentheses

Atom	x	y	z	U_{eq}
O(1)	−1342(2)	1749(1)	−3649(4)	.0290(11)
C(2)	−1322(2)	736(2)	−3542(6)	.0320(15)
C(3)	−559(2)	1279(2)	−2343(5)	.0205(12)
C(4)	514(2)	1377(2)	−3248(5)	.0207(12)
C(5)	945(2)	2369(2)	−2868(5)	.0211(13)
P(6)	986.8(4)	2615.6(4)	21(2)	.0157(3)
C(7)	−340(2)	2406(2)	782(5)	.0185(12)
C(8)	−686(2)	1423(2)	74(5)	.0206(11)
C(9)	1210(2)	3861(2)	366(5)	.0176(11)
C(10)	1668(2)	4178(2)	2281(5)	.0215(12)
C(11)	1833(2)	5134(2)	2600(6)	.0251(13)
C(12)	1556(2)	5773(2)	994(6)	.0256(13)
C(13)	1103(2)	5459(2)	−904(6)	.0263(14)
C(14)	917(2)	4511(2)	−1213(5)	.0227(13)
S(15)	1962(1)	1832.8(4)	1620(2)	.0204(3)

epoxide oxygen, i.e. axial or equatorial with respect to the attached ring system. An equatorial C—O bond seems to distort the oxirane ring to a small extent. A calculation of the intermolecular distance for the structure revealed no unusually short distances. The positional parameters for non-hydrogen atoms are given in Table VI.

EXPERIMENTAL

General Data. Melting points were determined with a Thomas-Hoover capillary apparatus and were uncorrected. The ^1H, ^{13}C, and ^{31}P NMR data were obtained on a Varian XL-100(15) NMR spectrometer equipped with a Nicolet TT-100 PFT accessory operating at 100.1 MHz with tetramethylsilane (TMS) as internal standard for ^1H NMR, at 25.2 MHz (with TMS) for ^{13}C and at 40.5 MHz (with 85% H_3PO_4) for ^{31}P. The ^{13}C and ^{31}P NMR spectra were obtained operating in the FT mode utilizing broad-band decoupling and off-resonance decoupling. Infrared spectral data were obtained on a Perkin Elmer 681 infrared spectrometer. Mass spectral data were collected on a high resolution CEC Model 21-110B HR mass spectrometer. Microanalyses were performed by Galbraith Microanalytical Laboratories, Knoxville, Tennessee. Reagents (commercially available) were purified before use where necessary. THF and ether were distilled from lithium aluminum hydride. DMSO was distilled from CaH_2.

1,6-Dioxaspiro[2.5]octane (**7a**). Sodium hydride (Aldrich, 50% in mineral oil; 1.60 g 0.033 mol) was washed thrice with 10-mL portions of petroleum ether (40–60°C) which were then removed from the dense sodium hydride powder with a pipet under N_2. To the above washed sodium hydride, still wet with petroleum ether, was added trimethyloxosulfonium chloride (4.40 g, 0.034 mol) and 35 mL of dry THF. The mixture was stirred under gentle reflux until the evolution of hydrogen ceased (ca. 1.5 h). A solution of 4-oxanone (**6a**) (Aldrich, 3.0 g, 0.03 mol) in THF (15 mL) was then added dropwise over a period of 30 min, keeping the reaction mixture at 50–55°C. The reaction mixture was stirred at 50–55°C for an additional 3 h and cooled to room temperature. A precipitate was filtered on a sintered funnel and washed with THF (3 × 5 mL). The filtrate and the washings were combined and concentrated under reduced pressure (water aspirator) to a volume of about 10 mL and diluted with 30 mL of ether. The ether layer was washed with water (2 × 5 mL), saturated sodium chloride solution (2 × 10 mL) and then dried (Na_2SO_4). Evaporation of ether and distillation of the residue through a vigreux column gave 1.2 g (35%) of the oxirane **7a** as a colorless oil, bp 30°C (2.0 mm). Anal. Calcd for $C_6H_{10}O_2$: 114.0680; Found: 114.0668.

1-Oxa-6-thiaspiro[2.5]octane (**7b**). A solution of dimethyloxosulfonium methylide in dimethyl sulfoxide was prepared as follows. Sodium hydride (2.06 g of a 50% dispersion in mineral oil, 0.043 mol) was washed with light petroleum ether as described above and added to trimethyloxosulfonium iodide (10.0 g, 0.046 mol) and DMSO (40 mL) under N_2. The mixture was stirred vigorously for 40 min at room temperature. A solution of 4-thianone (**6b**)[31] (5.0 g, 0.043 mol) in DMSO (20 mL) was added dropwise over a period of 30 min, and the new solution was stirred for another 2.5 h at room temperature. The reaction mixture was poured into water (700 mL), and the resulting solution was extracted with ether (3 × 50 mL). The ether extracts were combined and washed with water (2 × 30 mL) and with saturated solution of sodium chloride (2 × 20 mL) and then dried (Na_2SO_4). Evaporation of the ether gave an oil which solidified upon standing and was recrystallized (hexane) to give 4.30 g (76.8%) of **7b** as colorless needles, mp 52°C (lit.[32] 49–50°C). High resolution mass spec. M^+ (m/e) calcd for $C_6H_{10}OS$: 130.0452; Found: 130.0455.

6-Methyl-1-oxa-6-azaspiro[2.5]octane (**7c**). To a solution of dimethyloxosulfonium methylide in THF (40 mL), prepared from sodium hydride (0.045 mol) and trimethyloxosulfonium chloride (0.047 mol), was added dropwise to a solution of 1-methyl-4-piperidone (**6c**) (Aldrich, 4.60 g, 0.04 mol) in THF (20 mL) under N_2. The mixture was stirred at 50–55°C for 1 h and subsequently at room temperature for 5 h. Evaporation of the solvent left a residue which was treated with water (20 mL). The mixture was then extracted with ether (3 × 20 mL), and the extracts were combined and dried ($MgSO_4$). Removal of the ether and vacuum distillation of the residue gave the title oxirane **7c**, 4.0 g (77.4%), as a colorless oil; bp 68–70°C (0.1 mol). High resolution mass spec. M^+ (m/e) calcd for $C_7H_{13}NO$: 127.0997; Found: 127.0995.

6-Benzyl-1-oxa-6-azaspiro[2.5]octane (**7d**). A solution of 1-benzyl-4-piperidone (**6d**) (Aldrich 7.60 g, 0.04 mol) in dimethyl sulfoxide (10 mL) was added dropwise with stirring, under N_2, to a solution of dimethyloxosulfonium methylide prepared from sodium hydride (0.04 mol), trimethyloxosulfonium iodide (9.90 g, 0.045 mol) and dimethyl sulfoxide (35 mL). The mixture was stirred for 3 h at room temperature, poured into water (500 mL) and extracted with hexane (3 × 60 mL). The hexane extracts were combined, washed with water (3 × 50 mL) and dried (Na_2SO_4). Evaporation of the solvent gave a pale yellow oil. Distillation through a vigreux column gave pure 6-benzyl-1-oxa-6-azaspiro[2.5]octane (**7d**) 5.80 g (71.1%), bp 112°C (0.3 mm) [lit.[33] bp 93°C (0.06 mm)]. High resolution mass spec. M^+ (m/e) calcd for $C_{13}H_{17}NO$: 203.1310; Found: 203.1309.

Reaction of Dimethyloxosulfonium Methylide with 1-Phenyl-4-phosphorinanone (**6e**). *Preparation of* **7e**, **7l** *and* **7m**. The phosphorinanone (**6e**[34] (0.5 g, 2.60 mmol) was allowed to react with dimethyloxosulfonium methylide, prepared from NaH (3.0 mmol), trimethyloxosulfonium iodide (0.72 g, 3.3 mmol), and 10 mL of DMSO (as described above), and worked up (under N_2) to give 0.35 g of crude oxirane **7e**. The oxirane **7e** was extremely air sensitive and hence was converted to the benzyl bromide derivative as described below. The crude oxirane, 0.15 g (0.73 mmol), was dissolved in absolute methanol (3 mL), and benzyl bromide (0.26 g, 1.5 mmol) was added. The solution was stirred at room temperature (8 h under N_2). The solvent was then evaporated to give a white solid which was leached with dry ether (5 × 3 mL). Recrystallization (methanol–water) gave 0.18 g (66.7%) of bromide **7l**, mp 189–190°C. This bromide **7l** was hygroscopic and hence was converted to the corresponding hexafluorophosphate for analysis.

To a solution of the bromide **7l** (0.1 g, 0.27 mmol) in methanol (1 mL) was added a saturated solution of potassium hexafluorophosphate in water (0.2 mL), and the resulting solution was stirred at room temperature overnight. Evaporation of the solvents left a white solid which was recrystallized (methanol–water) to give the hexafluorophosphate **7m**, 0.065 g (55.3%), mp 174–175°C. Anal. Calcd for $C_{19}H_{22}F_6OP_2$: C, 51.59; H, 5.01; P, 14.01; Found: C, 51.87; H, 5.11; P, 13.97.

6-Phenyl-1-oxa-6-phosphaspiro[2.5]octane 6-Sulfide (**7f**). A solution of the dimethyloxosulfonium methylide was prepared under N_2 from sodium hydride (2.92 mmol), trimethyloxosulfonium iodide (0.65 g, 2.95 mmol) and DMSO (5 mL). The phosphorinanone **6f**[19] (0.47 g, 2.10 mmol) in DMSO (5 mL) was added dropwise at room temperature, with stirring, over a period of 20 min, and stirring was continued for 3 h. The reaction mixture was poured onto crushed ice (300 g) and left overnight. The precipitate was filtered, washed with water and dried. Recrystallization (methanol) gave 0.28 g (56%) of the oxirane **7f**, mp 161.5–162°C. High resolution mass spec. M^+ (m/e) calcd for $C_{12}H_{15}OPS$: 238.0581; Found: 238.0581.

Reaction of Dimethyloxosulfonium Methylide with r-2,cis-6-Diphenyl-4-oxanone (**6g**). *Preparation of* **7g**. Reaction of the oxanone **6g**[35] (1.0 g, 3.97 mmol) with the ylide generated from trimethyloxosulfonium iodide (1.0 g, 4.54 mmol), sodium hydride (4.50 mmol) and DMSO (10 mL) in the manner described for

the preparation of **7b**, afforded 0.71 g (67.6%) of the oxirane **7g** as shining flakes; mp 109–110°C (methanol). High resolution mass spec. M^+ (m/e) calcd for $C_{18}H_{18}O_2$: 266.1307; Found: 266.1301.

Trans-5,7-Diphenyl-1-oxa-6-thiaspiro[2.5]octane (**7h**). A solution of *r*-2,*cis*-6-diphenyl-4-thianone (**6h**)[10b] (5.36 g, 0.02 mol) in dimethyl sulfoxide (15 mL) was added via a hypodermic syringe under N_2 to a solution of dimethyloxosulfonium methylide generated from sodium hydride (0.02 mol), trimethyloxosulfonium iodide (4.84 g, 0.022 mol) and dimethyl sulfoxide (20 mL). The mixture was stirred at room temperature for (4 h) and then poured onto crushed ice (500 g). The precipitated oxirane **7h** was filtered, and washed with water and dried. Recrystallization (ethanol–water) gave *trans*-5,7-diphenyl-1-oxa-6-thiaspiro[2.5]octane (**7h**), 4.60 g (81.6%), mp 125–126°C. High resolution mass spec. M^+ (m/e) calcd for $C_{18}H_{18}OS$: 282.1078; Found: 282.1078.

Trans-5,7-Diphenyl-cis-4,8-dimethyl-1-oxa-6-azaspiro[2.5]octane (**7i**). Dimethyloxosulfonium methylide was prepared as described above from NaH (3.75 mmol), trimethyloxosulfonium iodide (0.88 g, 4.0 mmol), DMSO (10 mL) (under N_2) and a solution of *r*-2,*cis*-6-diphenyl-*trans*-3,5-dimethyl-4-piperidone[36] (**6i**) (0.63 g, 2.26 mmol) in DMSO (5 mL). The mixture was stirred at room temperature (12 h) and poured into water (300 mL). The precipitated oxirane was filtered, washed with water and dried. Recrystallization (ethanol) gave shining needles of the oxirane **7i**, 0.43 g (65.2%), mp 129–130°C. High resolution mass spec. M^+ (m/e) calcd for $C_{20}H_{23}NO$: 293.1780; Found: 293.1771.

Reaction of Dimethyloxosulfonium Methylide with 2,2,6,6-Tetramethyl-4-piperidone (**6j**). *Preparation of* **7j**. 2,2,6,6-Tetramethyl-4-piperidone (**6j**)[37] (4.20 g, 0.027 mol) was allowed to react with the ylide prepared from NaH (0.03 mol) and trimethyloxosulfonium chloride (3.90 g, 0.031 mol) in THF (50 mL) under N_2. After stirring the mixture under gentle reflux for 6 h, the solvent was evaporated and 20 mL of water was added. The mixture was extracted with ether (3 × 30 mL) and the etheral extracts were combined and dried ($MgSO_4$). Evaporation of ether and vacuum distillation of the residue gave 3.50 g (76.4%) of the oxirane **7j**, as a colorless oil, bp 51°C (1.5 mm). High resolution mass spec. M^+ (m/e) calcd for $C_{10}H_{19}NO$: 169.1467; Found: 169.1499.

Reaction of Dimethyloxosulfonium Methylide with 2,2,6,6-Tetramethyl-1-phenyl-4-phosphorinanone 1-Sulfide (**6k**). *Preparation of* **7k**. A solution of the phosphorinanone **6k**[38] (3.0 g, 10.71 mmol) in 10 mL of DMSO was added to the ylide generated by the reaction of sodium hydride (12.92 mmol) and trimethyloxosulfonium iodide (2.86 g, 13.00 mmol) in DMSO (10 mL) under N_2. The mixture was stirred at 30–35°C (7 h) and poured onto crushed ice (500 g). The oxirane **7k**, which precipitated as a white powder, was filtered, washed with water and dried. Recrystallization (methanol) gave oxirane **7k**, 2.20 g (69.8%), as shining flakes; mp 171–172°C. High resolution mass spec. M^+ (m/e) calcd for $C_{16}H_{23}OPS$: 294.1207; Found: 294.1208.

Reaction of Dimethyloxosulfonium Methylide with r-2,cis-6-Diphenyl-4-thianone (**6h**). *Preparation of* **11**. The ylide was generated from NaH (6.25 mmol), trimethyloxosulfonium iodide (5.0 g, 0.023 mol) and DMSO (35 mL) under N_2 as described above. The thianone **6h**[10b] (1.0 g, 3.73 mmol) in DMSO (15 mL) was added dropwise to the ylide over a period of 20 min, and the new mixture was stirred at room temperature (1 h) and then at 55–60°C (5 h). The reaction mixture was cooled to room temperature and poured into water (500 mL) and extracted with ether (2 × 50 mL). The ether extracts were combined, washed with water (3 × 50 mL) and dried (Na_2SO_4). Removal of ether gave a white solid which was recrystallized (ethanol–water) to give 0.50 g (33.3%) of the tertiary alcohol **11** as colorless needles, mp 106–107°C; IR (KBr) 3530 (O—H), 1030 cm^{-1} (C—OH). ^1H NMR ($DCCl_3$) δ 1.86 (s, 1 H, OH, exchangeable), 2.07 [d, 2 H, $H(3_e)$, $H(5_e)$, J = 11.0 Hz], 2.30 [dd, 2 H, $H(3_a)$ $H(5_a)$, J = 13.0 and 3.0 Hz] and 7.18–7.50 (m, 10 H, ArH); ^{13}C NMR ($DCCl_3$) ppm 24.54 ($\underline{C}H_2I$), 43.95 [C(3), C(5)], 44.15 [C(2), C(6)], 69.77 [C(4)], 126.94, 127.25, 128.31, 140.36 (Ar—C). High resolution mass spec. M^+ (m/e) calcd for $C_{18}H_{19}IOS$: 410.0203; Found: 410.0218. Anal. Calcd for $C_{18}H_{19}IOS$: C, 52.69; H, 4.67; S, 7.81; Found: C, 52.65; H, 4.83; S, 7.81.

Reaction of Dimethyloxosulfonium Methylide with r-2,trans-6-Diphenyl-4-thianone (**9**). *Preparation of* **7h**. To a solution of the ylide, prepared from NaH (3.96 mmol), trimethyloxosulfonium iodide (1.0 g, 4.55 mmol) and DMSO (20 mL) under N_2 as described above, was added a solution of *r*-2,*trans*-6-diphenyl-4-thianone (**9**)[10b] (1.0 g, 3.73 mmol) in DMSO (10 mL). The mixture was stirred at room temperature (3 h) and poured onto crushed ice (300 g). The precipitated solid was filtered, washed profusely with water and dried. Recrystallization (ethanol–water) gave 0.8 g (76.2%) of the oxirane **7h** as needles, mp 125–126°C. ^1H NMR ($DCCl_3$) δ 1.62–1.90 [dd, 2 H, $H(4_a)$, $H(8_a)$, J = 13.0 and 3.0 Hz], 2.58 [pseudo triplet, 2 H, $H(4_e)$, $H(8_e)$, J = 12.0 Hz], 2.72 [s, 2 H, H(2)], 4.44 [dd, 2 H, H(5), H(7), J = 12.0 Hz and 3.0 Hz] and

7.00–7.50 [m, 10 H, ArH]; ^{13}C NMR ($DCCl_3$) ppm 41.29 [C(4), C(8)], 46.13 [C(5), C(7)], 54.51 [C(2)], 57.78 [C(3)], 127.14, 127.32, 128.34, 140.44 (Ar—C). High resolution mass spec. M^+ (m/e) calcd for $C_{18}H_{18}OS$: 282.1078; Found: 282.1078. This product was identical with the oxirane obtained from the thianone **6h**.

Reduction of 1-Oxa-6-thiaspiro[2.5]octane (**7b**). *Preparation of Alcohol* **8a**. To a well-stirred slurry of $LiAlH_4$ (0.6 g, 15.79 mmol) in anhydrous ether (20 mL) under N_2 was added a solution of the oxirane **7b** (1.0 g, 7.69 mmol) in dry ether (10 mL). The mixture was stirred under gentle reflux for 2 h. Excess hydride was *carefully* destroyed by a dropwise addition of ice-cold water (10 mL), and the mixture was neutralized with hydrochloric acid (5%, 10 mL). The mixture was then extracted with ether (2 × 20 mL). The ether extracts were combined and washed with saturated sodium bicarbonate solution, water and dried (Na_2SO_4). Evaporation of ether and distillation of the residue gave a viscous oil, bp 51–52°C (0.8 mm) [lit.[39] 54–55°C (1.0 mm)] which solidified to a waxy solid upon standing. The waxy solid sublimed at 40–45°C (1.0–2.5 mm) to give 0.62 g (61.1%) of the alcohol **8a** as colorless needles, mp 46°C (lit.[40] mp 45.5°C). IR (KBr) 1115 cm^{-1} (C—OH); ^1H NMR ($DCCl_3$) δ 1.22 (s, 3 H, CH_3), 1.64–2.00 [m, 4 H, H(3), H(5)], 2.16 (s, 1 H, OH), 2.30–3.10 [m, 4 H, H(2), H(6)]; ^{13}C NMR ($DCCl_3$) ppm 24.31 [C(2), C(6)], 30.29 [CH_3], 39.52 [C(3), C(5)], 67.79 [C(4)]. High resolution mass spec. M^+ (m/e) calcd for $C_6H_{12}OS$: 132.0609; Found: 132.0606.

Reduction of 6-Benzyl-1-oxa-6-azaspiro[2.5]octane (**7d**) *with Lithium Aluminum Hydride. Preparation of Alcohol* **8b**. A solution of the oxirane **7d** (5.70 g, 0.028 mol) in dry ether (30 mL) was added dropwise to a vigorously-stirred suspension of lithium aluminum hydride (1.33 g, 0.035 mol) in ether (30 mL) under N_2. The mixture was stirred under gentle reflux for 3 h, cooled to room temperature and the excess hydride was destroyed (CAUTION!) by adding ice cold water (35 mL). The ether layer was decanted from the aqueous phase and the aqueous layer was washed with ether (3 × 15 mL). The ether layer and the ether washings were combined and dried (Na_2SO_4). Evaporation of ether and Kugelrohr distillation [oven temperature 110–120°C (0.5 mm)] of the residue gave 5.0 g (87.0%) of the tertiary alcohol **8b** as a viscous liquid. A sample for analysis was prepared as follows. The oil was dissolved in 1 : 1 methanol : H_2O (15 mL) and refrigerated for 24 h. Alcohol **8b** precipitated as white needles mp 63–64°C. IR (KBr) 1120 cm^{-1} (C—OH); ^1H NMR ($DCCl_3$) δ 1.16 (s, 3 H, CH_3), 1.40–1.68 [m, 4 H, H(3), H(5)], 2.20–2.66 [m, 5 H, H(2), H(6), OH], 3.45 [s, 2 H, $CH_2C_6H_5$], 7.04–7.36 [m, 5 H, ArH]; ^{13}C NMR ($DCCl_3$) ppm 29.33 [CH_3], 38.52 [C(3), C(5)], 49.64 [$CH_2C_6H_5$, C(6)], 62.91 [$CH_2C_6H_5$], 67.52 [C(4)], 137.94, 128.98, 127.89, 126.70 [Ar—C]. High resolution mass spec. M^+ (m/e) calcd for $C_{13}H_{19}NO$: 205.1467; Found: 205.1461.

Reduction of trans-5,7-Diphenyl-1-oxa-6-thiaspiro[2.5]octane (**7h**) *with Lithium Aluminum Hydride. Preparation of Alcohol* **8c**. Lithium aluminum hydride (0.05 g, 1.32 mmol) was slowly added to 15 mL of dry ether in a 50 mL flask equipped with a condenser, addition funnel, magnetic stirrer and N_2 inlet. Oxirane **7h** (0.3 g, 1.06 mmol) was dissolved in 10 mL of dry ether, and the solution was added dropwise during a period of 15 min to the slurry. After the addition was complete, the reaction mixture was gently boiled (3 h) and subsequently cooled to room temperature. Excess hydride was destroyed by the careful addition of ice cold water (10 mL). The hydrolyzed mixture was extracted with ether (2 × 10 mL), and the ether layers were combined and dried (Na_2SO_4). Removal of ether gave an oil which solidified upon standing. Purification by recrystallization (benzene/hexane) gave 0.25 g (83.3%) of the alcohol **8c**, mp 85–86°C. IR (KBr) 1120 cm^{-1} (C—OH); ^1H NMR ($DCCl_3$) δ 1.32 (s, 3 H, CH_3), 1.50 (s, 1 H, OH), 1.78–2.20 [m, 4 H, H(3), H(5)], 4.40–4.60 [dd, 2 H, H(2), H(6), J = 10.5 and 4.0 Hz], 7.16–7.50 [m, 10 H, ArH]; ^{13}C NMR ($DCCl_3$) ppm 32.45 [CH_3], 43.83 [C(3), C(5)], 46.31 [C(2), C(6)], 70.24 [C(4)], 141.21, 128.34, 127.40, 127.14 [Ar—C]. High resolution mass spec. M^+ (m/e) calcd for $C_{18}H_{20}OS$: 284.1235; Found: 284.1247.

Reaction of 4-Thianone (**6b**) *with Methylmagnesium Iodide. Preparation of* **8a**. To methylmagnesium iodide [from magnesium (0.28 g, 0.012 g at) and methyl iodide (1.71 g, 0.012 mol)] at 0°C in dry ether (20 mL) was added 4-thianone[31] (0.70 g, 0.006 mol) in dry ether (15 mL), and the reaction mixture was stirred (3 h) under N_2. This mixture was gradually allowed to reach room temperature (after about 2 h) and was stirred for an additional 3 h. The product was hydrolyzed with 5% sulfuric acid (10 mL) at 0°C, and the mixture was extracted with ether (2 × 10 mL). The ether layers were combined, washed with saturated solution of sodium bicarbonate, water and dried (Na_2SO_4). Removal of ether and distillation of the residue gave 4-methylthian-4-ol (**8a**), 0.7 g (87.9%), as an oil, bp 51–52°C (0.8 mm) [lit.[39] 54–55°C (1.0 mm)]. Upon standing, the oil solidified, and the solid was sublimed (40–45°C/1–2.5 mm) to give colorless needles, mp 46°C. This product was identical with the alcohol obtained by the reduction ($LiAlH_4$) of the oxirane **7b**.

Reaction of 1-Benzyl-4-piperidone (**6d**) *with Methyllithium. Preparation of* **8b**. A solution of the piperidone **6d** (1.0 g, 5.29 mmol) in dry ether (10 mL) was added to an ice-cold solution of methyllithium [1.8 M solution in ether (12 mL, 21.60 mmol)] dropwise under N_2. The mixture was stirred under gentle reflux for 5 h. After cooling with a freezing mixture, 15 mL of ice cold water was added with *extreme care* to destroy excess methyllithium. The resulting mixture was extracted with ether (3 × 15 mL). The ether extracts were combined, washed with water (2 × 20 mL) and dried (Na_2SO_4). Evaporation of ether gave a viscous liquid, which upon Kugelrohr distillation [oven temperature 110–120°C (0.5 mm)], gave the alcohol **8b**. The oil was dissolved in 1 : 1 methanol : H_2O (5 mL) and left in a refrigerator for 24 h where-upon the tertiary alcohol **8b** precipitated as white needles. The solid was filtered and dried to yield 0.8 g (74.1%) of **8b**, mp 63–64°C. This alcohol was found to be identical with the product obtained by the reduction of the oxirane **7d**.

Reaction of r-2,cis-6-Diphenyl-4-thianone (**6h**) *with Methylmagnesium Iodide. Preparation of Alcohol* **8c**. A solution of methylmagnesium iodide was prepared from magnesium (0.28 g, 0.012 g at) and methyl iodide (1.71 g, 0.012 mol) in dry ether (20 mL) under N_2 and cooled to 0°C. A solution of the thianone **6h**[10b] (1.60 g, 0.006 mol) in dry ether (20 mL) was added dropwise, and the mixture was stirred under reflux for 8 h. This reaction mixture was cooled to room temperature and poured onto crushed ice (200 g). The mixture was made acidic (pH ~ 5–6) with 5% H_2SO_4 (10 mL) and extracted with ether (2 × 20 mL). The ether layers were combined, washed with saturated solution of sodium bicarbonate, water and dried (Na_2SO_4). Evaporation of ether gave a solid, which upon fractional crystallization (benzene/hexane), gave the alcohol **8c**, 1.4 g (82.6%), mp 85–86°C, which was found to be identical with the tertiary alcohol obtained by the reduction of the oxirane **7h** with lithium aluminum hydride.

Single Crystal Analysis. The crystals of compound **7f**, obtained from methanol, were in general of poor quality. A small plate (.15 × .10 × .05 mm), which showed sharp extinctions under the polarizing microscope, was selected for the X-ray investigation. All X-ray measurements were carried out at −135(2)°C on a Nonius CAD-4 automatic diffractometer fitted with a low-temperature (liquid N_2) cooling device. Systematic absences showed the space group to be Pna21 or Pnam. The former was proven to be correct by the solution of the structure. The unit cell dimensions were obtained by a least-squares fit to $+2\theta$ and -2θ values of 48 reflections measured at low temperature using CuKα_1 (λ = 1.54051 A) radiation. The density was determined by floatation in an aqueous potassium iodide solution. The crystal data are listed in Table IV.

The intensities of all unique reflections with $2\theta \leqslant 150°$ were measured using the θ–2θ scan technique. The relevant data collection parameters are listed in Table IV. Other information for the data collection procedure have been reported earlier.[40] In all, 1293 reflection intensities were measured, of which 49 had intensities less than $2\sigma(I)$ and were considered unobserved. Intensities were corrected for Lorentz and polarization factors, but no absorption correction was made. Each structure amplitude was assigned an experimental weight $w_F = 1/\sigma_F^2$, where σ_F was obtained from counting statistics.[41]

The positions of the phosphorus and the sulfur atoms were obtained from a three-dimensional Patterson map. The complete structure was determined by applying the heavy atom technique. All hydrogen atoms were located from a difference Fourier map. The structure was refined by the least-squares method with anisotropic thermal parameters for all non-hydrogen atoms, and isotropic thermal parameters for the hydrogen atoms. The effect of anomalous dispersion of Cu radiation by sulfur and phosphorus atoms was taken into account. The final R factor for 1247 reflections included into least-squares calculations is 0.031, and it is 0.037 for all 1293 reflections. The scattering factors for P, S, C and O atoms were taken from the International Tables for X-ray Crystallography (1974)[42] and those of hydrogen were from Stewart, Davidson and Simpson (1965).[43] The final positional parameters of non-hydrogen atoms are given in Table VI, and those of hydrogen atoms in the supplementary material.

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45. The atomic coordinates for this work are available on request from the Director of the Cambridge Crystallographic Data Centre, University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW. Any request should be accompanied by the full literature citation for this communication.

The following data are deposited: hydrogen atom parameters; anisotropic thermal parameters ($\times 10^4$); anisotropic thermal parameters ($\times 10^4$) in the form $T = \exp\{-2\pi^2(a^{*2}U_{11}h^2 + \cdots + 2a^*C^*U_{13}hl)\}$. Hydrogen positional parameters ($\times 10^4$). Observed and calculated structure factors for $C_{12}H_{15}OPS$.