Chiral Ligands for Organometallic Catalysis containing Two Dioxolane Rings

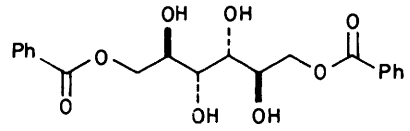
John M. Brown * and Fabian M. Dayrit
Dyson Perrins Laboratory, South Parks Road, Oxford OX1 3QY
Denis Sinou
Laboratoire de Chimie Organique II, Université Claude Bernard, Villeurbanne 69621, France

Treatment of D-mannitol 1,6-dibenzoate with a catalytic quantity of toluene-*p*-sulphonic acid in 2,2-dimethoxypropane leads to the formation of two cyclic acetals, 4*R*,8*R*,9*R*,10*R*-2,2',6,6'-tetramethyl-4,8-bis(benzoyloxymethyl)-1,3,5,7-tetraoxadecalin and *R*,*R*'-4,4'-bi-(2,2-dimethyl-5-benzoyloxymethyldioxolanyl) in comparable amounts. Successive reaction with sodium methoxide in methanol, methanesulphonyl chloride, and lithium or potassium diphenylphosphide gave the corresponding phosphines namely 4*S*,8*S*,9*S*,10*S*-2,2',6,6'-tetramethyl-4-8-di[bis(diphenylphosphino)methyl]-1,3,5,7-tetraoxadecalin and *S*,*S*-4,4'-bi-[2,2-dimethyl-5-bis(diphenylphosphino)methyldioxolanyl]. Similarly, starting from L-iditol, the diphosphines 4*R*,8*S*,9*S*,10*R*-2,2',6,6'-tetramethyl-4,8-di[bis-(diphenylphosphino)methyl]-1,3,5,7-tetraoxadecalin and *S*,*R*-4,4'-bi-[2,2-dimethyl-5-bis(diphenylphosphino)methyldioxolanyl] were obtained. It was demonstrated through ^{31}P n.m.r. studies that both *cis*- and *trans*-chelate complexes of rhodium were formed by these biphosphine ligands. Their potential in asymmetric hydrogenation was demonstrated, for low to moderate yields of amino acids were formed from a variety of enamide precursors.

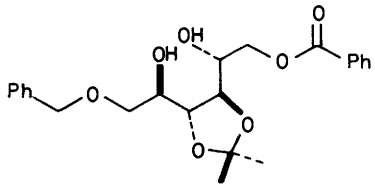
Effective catalysis of asymmetric hydrogenation requires rhodium complexes of chelate biphosphines, and an olefinic reactant carrying a secondary functional group capable of co-ordination.[1] With certain exceptions,[2] the highest optical yields are obtained with chiral bisphosphinoethane derivatives although their success is largely limited to the reduction of dehydroamino acids. Bisphosphinobutane complexes, exemplified by those of the archetypal ligand diop,[3]† tend to give lower optical yields but with greater versatility and a wider range of substrates can be reduced with moderate asymmetric induction.

Complexes of chiral chelate ligands with more than seven atoms in the ring are rarer and little is known about their effectiveness in asymmetric catalysis.[4] Given the right backbone, it might be that the greater 'bite' angle at rhodium brought about by the larger chelate ring[5] would encourage a stronger steric interaction with the substrate, and hence a higher selectivity. The object of the present work was to synthesise ligands related to diop with an additional dioxolane ring in the interphosphine chain.

Synthetic Routes to the Biphosphines.—Mannitol 1,6-dibenzoate (**1**) is readily available and under normal conditions reacts with acetone to form the symmetrical monodioxolane (**2**),[6] not subject to further reaction even under forcing conditions. Its reaction with an excess of 2,2-dimethoxypropane catalysed by toluene-*p*-sulphonic acid proceeded cleanly to a mixture of bis-dioxolanes (**3**) and (**4**) easily separable by silica chromatography. The structures of these two compounds follows from their ^{1}H and ^{13}C n.m.r. spectra with the respective ^{13}C chemical shift of the quaternary carbon at δ 109.8 p.p.m. for (**3**) and at δ 101.1 p.p.m. for (**4**) being instrumental in their distinction.[7] The remainder of the synthetic procedure is illustrated, and is straightforward to the point of preparation of methane- and toluene-*p*-sulphonates (**5b,c**) and (**6b,c**). Based on a considerable number of trial attempts, phosphination was carried out employing the methanesulphonates, by reaction with pre-formed lithium or potassium diphenylphosphide in tetrahydrofuran. The product (**7**) was an oil which was



(1)



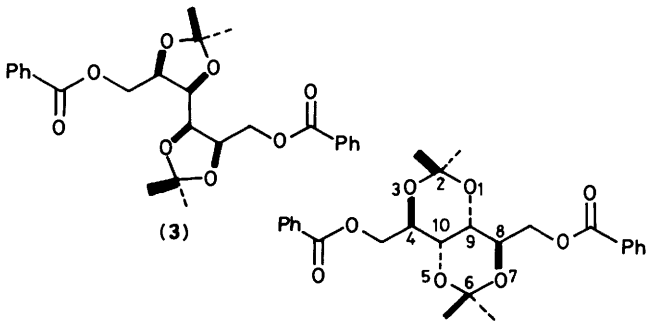
(2)

essentially pure by ^{31}P n.m.r. when starting from (**5b**) whereas the alternative product (**8**) derived from (**6b**) was a readily purified crystalline solid.

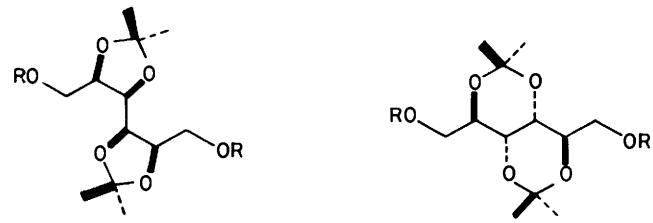
L-Iditol can be obtained by catalytic hydrogenation of sorbose, then separation from its stereoisomer L-sorbitol by fractional crystallisation of the hexa-acetate, followed by hydrolysis.[8] Attempted preparation of L-iditol 1,6-dibenzoate by the procedure which had been successfully employed in the synthesis of (**1**) consistently led to an impure product, which appeared to be mainly (**9**) on the basis of spectroscopic evidence. Using the same procedures as before, this was converted directly into the toluene-*p*-sulphonates (**10b**) and (**11b**), whose separate reaction with potassium diphenylphosphide in tetrahydrofuran gave rise to the five-membered-ring diacetonide (**12**) and the six-membered-ring diacetonide (**13**). Both were solids, which were readily purified by recrystallisation from methanol and were then pure by ^{31}P n.m.r.

^{31}P N.m.r. Studies on their Rhodium Complexes.—In these structural studies more attention was paid to the five-membered ring diacetonides (**7**) and (**12**) because of their resemblance to the monoacetonide diop. Using conventional techniques[9] for the preparation of norbornadienerhodiumbiphosphine complexes, neither ligand gave rise to an isolable species. Their presence in solution was inferred by ^{31}P n.m.r. when the

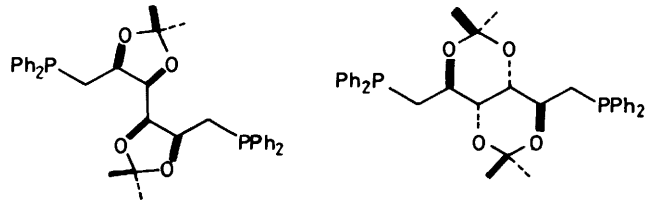
† diop is 2,2-dimethyl-4,5-bis(diphenylphosphinomethyl)-1,3-dioxolane.



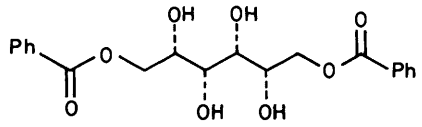
(3) (4)



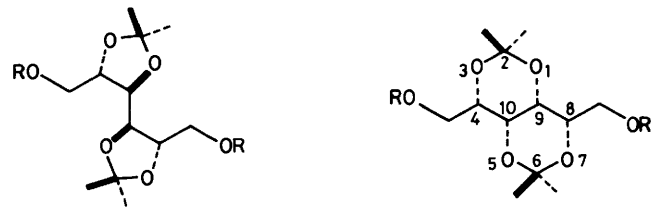
(5) a; R = H (6)
b; R = SO_2CH_3
c; R $SO_2C_6H_4CH_3$-*p*



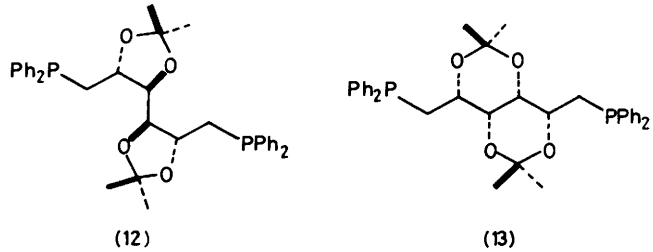
(7) (8)



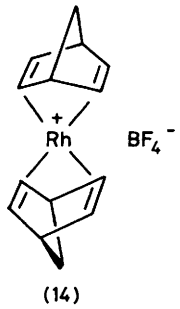
(9)



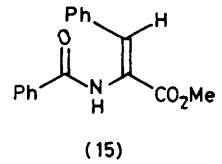
(10) a ; R = H (11)
b ; R = $SO_2C_6H_4CH_3$



(12) (13)



(14)



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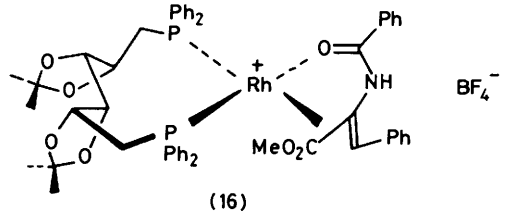


(16)

biphosphine was mixed with an equimolar quantity of the precursor complex (**14**) (Table 1). Observations made on hydrogenation of these solutions and subsequent addition of dehydroamino acid derivatives are summarised in Table 1. *trans*-Chelating biphosphines give rise to rhodium dihydride complexes on hydrogenation in methanol whereas *cis*-chelating biphosphines give rise to solvate complexes.[10] Under 1 atm. of H_2, the mannitol derived biphosphine (**7**) gave a solvate whereas the iditol-derived biphosphine (**12**) gave rise to a dihydride. The addition of methyl *Z*-α-benzamidocinnamate (**15**) gave a spectrum typical of an enamide complex in the latter case. The latter bore a particularly close resemblance to the corresponding complex of diop[11] and was formed with high stereospecificity.

The availability of six-membered-ring acetonides (**8**) and (**13**) encouraged a parallel study. In both cases a *trans*-dihydride was formed on hydrogenation of the norbornadiene complexes (Table 2) with no evidence for solvate production.

Catalytic Hydrogenation by the Rhodium Complexes.—A series of hydrogenations of dehydroamino acid derivatives was carried out and although reactions were uniformly fast the optical yields were disappointing. Results are recorded in Table 2, and include examples of dehydrodipeptide reduction.[12] With the 5,5-diacetonide derived from mannitol (**7**) the highest enantiomer excess obtained was 42%, considerably greater than its counterpart (**12**) derived from iditol. This is despite a prediction that the transoid arrangement of the dioxolane rings in (**12**) should be conducive to a high degree of stereochemical recognition, based on the inspection of molecular models and reinforced by the stereospecificity observed in formation of (**16**). Obviously the inherent flexibility of the nine-membered-ring chelate is counterproductive to optical specificity; the advantages of chelate rigidity have been pointed out elsewhere.[13] The problem is not an insuperable one, and bridging acetals might be employed to lock the favoured conformation of complexes related to (**16**).

Some experiments were carried out with the six-membered-ring diacetonides and the iditol derivative gave surprisingly fair optical yields.

Experimental

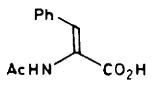
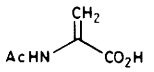
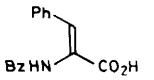
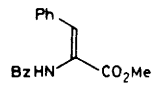
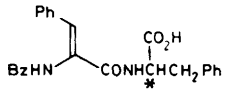
All manipulations involving air-sensitive species were carried out in Schlenk apparatus under dry argon. Solvents were purified by standard procedures and thoroughly degassed before use. ^1H N.m.r. spectra were recorded on a Bruker

Table 1. ^{31}P N.m.r. spectra of rhodium complexes

Structure	Diolefin complex	Reaction product with H_2–MeOH	Enamide complex
(a) From D-mannitol			
(7)	From bicyclo[2.2.1]heptadiene[a,b] δ_{P_A} 28.0, δ_{P_B} 13.7 p.p.m. ($J_{P_AP_B}$ 30, J_{P_APh} J_{P_BRh} = 154 Hz) From cyclo-octa-1,5-diene[c] δ 16.5 p.p.m. (J_{PRh} 150 Hz)	Solvate δ 53.2 p.p.m. (J_{PRh} 206 Hz) Solvate as above	
(8)	From bicyclo[2.2.1]heptadiene[a,d] δ 20.3 p.p.m. (J_{PRh} 153 Hz)	Dihydride[e] δ 32.1 p.p.m. (J_{RhP} 119 Hz)	From methyl Z-α-benzamidocinnamate[f] A δ_{P_A} 31.0, δ_{P_B} 8.5 p.p.m. (J_{P_ARh} 155, J_{P_BPh} 155, $J_{P_AP_B}$ 48 Hz) B δ_{P_A} 28.7, δ_{P_B} 27.3 p.p.m.) (J_{P_ARh} 157, J_{P_BPh} 167, $J_{P_AP_B}$ 49 Hz)
(b) From L-iditol			
(12)	From bicyclo[2.2.1]heptadiene[a] δ 23.6 p.p.m. (J_{PRh} 153 Hz)	Dihydride δ 30.2 p.p.m. (J_{RhP} 119 Hz)	From methyl Z-α-benzamidocinnamate[g] δ_{P_A} 32.3, δ_{P_B} 9.0 p.p.m. (J_{P_ARh} 154, J_{P_BRh} 159, $J_{P_AP_B}$ 46 Hz)
(13)	δ_{P_A} 27.6, δ_{P_B} 11.3 p.p.m. (J_{P_ARh} J_{P_BPh} 154, $J_{P_AP_B}$ 29 Hz)	Dihydride δ 33.4 p.p.m. (J 118 Hz)	

[a] Complexes were prepared *in situ* from the biphosphine and bis(bicyclo[2.2.1]heptadiene)rhodium tetrafluoroborate. Attempted isolation using this and other methods of preparation was not successful. [b] The origin of P_A,P_B inequivalence is unknown but it has been observed with other oxygenated biphosphines and may be a case of *O*-co-ordination. [c] Prepared from the biphosphine and cyclo-octa-1,5-dienerhodium acetylacetonate in the presence of HBF_4. [d] Minor species with similar δ and J_{PRh} values were apparent. [e] At ambient temperature a broad hydride signal was observed at δ_H 22.8. [f] The two diastereoisomeric species A and B were present in comparable proportion. [g] Single species, with sharp spectrum at room temperature.

Table 2. Reduction of dehydroamino acids and esters catalysed by rhodium biphosphine complexes

Substrate	Biphosphine	Enantiomer excess	Method
	7	18 *S*	A,B
	8	0	C
	12	15 *S*	B
	13	25.5 *R*	B
	7	28	A
	8	2 *S*	C
	8	14 *S*	B
	12	13 *S*	B
	13	44 *R*	B
	7	5 *S*	
	8	12 *R*	
	12	4 *S*	
	13	22 *R*	
	12	13% (*S* ⟶ *RS*)	B
	12	11% (*R* ⟶ *RR*)	B
	7	0 (*R* ⟶ *RR*)	B
	7	42% (*S* ⟶ *RS*)	B

Reactions were carried out at 20 °C and 1 atm. H_2 in methanol solution employing bis(bicyclo[2.2.1]heptadiene)rhodium tetrafluoroborate (4.7 mg, 0.013 mmol) and biphosphine (7.2 g, 0.0125 mmol) together with a 50 molar excess of substrate. The mixture was stirred until no further H_2 was absorbed (usually < 1 h). Preparation of the catalyst *in situ* employing cyclo-octadienerhodium acetylacetonate gave similar results. Methods of analysis: A, chiral column gas-chromatography (after ref. 14); B, ^1H n.m.r. analysis of the methyl ester in the presence of chiral shift reagent [15] Eu(hfc)$_3$; C, optical rotation. Experiments carried out in the presence of trimethylamine [16] led to the suppression of catalysis.

WH300 spectrometer and ^{31}P n.m.r. spectra on the same instrument or alternatively on a Bruker WH90 spectrometer. The preparation of samples for *in situ* hydrogenation experiments has been described previously.[10,11]

Optical rotations were measure on a Perkin-Elmer 241 polarimeter. Microanalyses were performed by Dr. F. B. Strauss, Oxford.

Preparation of 4R,8R,9R,10R-2,2′6,6′-*tetramethyl*-4,8-*bis*-(*benzoyloxymethyl*)-1,3,5,7-*tetraoxadioxolane*.—To a solution of 1,6-dibenzoyl-D-mannitol (5.10 g, 13.1 mmol), m.p. 181—182 °C, in 2,2-dimethoxypropane (200 ml; distilled off Na_2SO_4) was added anhydrous toluene-*p*-sulphonic acid (0.2 g) and the mixture stirred at room temperature for 30 h with protection from moisture. After neutralisation with anhydrous sodium carbonate it was then filtered and concentrated, dissolved in diethyl ether (200 ml) and washed with brine (2 × 100 ml). The ether extract was dried (Na_2SO_4), and concentrated to a yellow oil (6.05 g, 98%). The crude material was purified in portions by flash chromatography (1.3 g, to 150 g silica; 60μ Merck), eluting with diethyl ether–light petroleum (b.p. 40—60 °C) (30:70; 1 200 ml, then 60:40; 400 ml) and collecting 30 ml fractions. Progress was monitored by t.l.c. and two pure components thus separated in fractions 5—14 and 19—31. Solvent was removed *in vacuo* from the first set giving 4*R*,8*R*,9*R*,10*R*-2,2′,6,6′-tetramethyl-4,8-bis(benzoyloxymethyl)-1,3,5,7-tetraoxadecalin (0.413 g) as an oil, δ_H (300 MHz; $CDCl_3$) 8.05 (dd, *o*-Ar, 2 H), 7.57 (tt, *m*-Ar, 1 H), 7.43 (dt, *p*-Ar, 1 H), 4.60, 4.47 (br, m, CH_2O, CHO, 4 H), 1.56, 1.39 (s, s, CH_3, 6 H); δ_C ($CDCl_3$; 22.63 MHz), 166.3 (CO), 133.0, 130.0, 128.3 (Ar), 101.1 [$(CH_3)_2$], 68.4, 68.1, 64.7 (CH_2O), 24.4, and 23.5 (CH_3) p.p.m., which was used directly in the next stage.

The second set of fractions was combined and concentrated *in vacuo* to give *R*,*R*-4,4′-bi-(2,2-dimethyl-5-benzoyloxymethyl-dioxolanyl) (0.468 g) as an oil, δ_H (300 MHz; $CDCl_3$) 8.05 (dd, *o*-Ar, 2 H), 7.60 (H, *m*-Ar, 1 H), 7.45 (dt, *p*-Ar, 1 H), 4.52 (1 H, dd, CH_2O, $J_{1,1'}$ 12, $J_{1,2}$ 3 Hz), 4.43 (1 H, dd, CH_2O, $J_{2,2'}$ 7 Hz), 4.11 (1 H, m, CHO, H_2), 3.12 (1 H, br, d, 3-H, $J_{2,3}$ 8 Hz), 1.45 (s, CH_3); δ_C (22.63 MHz; $CDCl_3$) 166.5 (C), 133.5, 130.4, 129.9, 128.9 (Ar), 109.8 [$(CH_2)_2$], 75.6, 74.6, 64.6 (CHO), 27.5, and 25.5 (CH_3) p.p.m.

To a solution of sodium methoxide (from 0.051 g Na) in dry methanol (90 ml) there was added the diester (0.413 g) and the mixture stirred for 16 h, when monitoring by t.l.c. (silica; diethyl ethyl–light petroleum 4:1) indicated that starting material had been consumed. Neutralisation was achieved by pouring the

reaction mixture into saturated aqueous $NaHCO_3$ (40 ml) and extracting with CH_2Cl_2 (5 × 80 ml). The combined organic extract was washed with water once, concentrated on a rotary evaporator, dried (Na_2SO_4), and the remaining solvent removed *in vacuo*. There was thus obtained 4*R*,8*R*,9*R*,10*R*-2,2′,6,6′-tetramethyl-4,8-bis(hydroxymethyl)-1,3,5,7-tetraoxadecalin (0.109 g, 47%) as an oil, δ_H ($CDCl_3$; 22.63 MHz) 100.8 [$(CH_3)_2$], 70.1, 67.6, 62.8 (CHO), 24.7 and 23.7 (CH_3) p.p.m.

To a solution of this diol (0.064 g, 0.24 mmol) in pyridine (5 ml) was added toluene-*p*-sulphonyl chloride (0.4 g, 0.75 mmol) and the mixture was left for 18 h at 5 °C. Distilled H_2O (80 ml) was added and the solution maintained at 5 °C until crystallisation was complete. The product was filtered and washed with diluted aqueous HCl and water. Excess of water was removed by entrainment with EtOH giving 4R,8R,9R,10R-2,2′,6,6′-*tetramethyl*-4,8-*bis*-(p-*tolylsulphonyloxymethyl*)-1,3,5,7-*tetraoxadecalin* (0.0654 g, 49%), m.p. 141—142 °C, (Found: C, 54.9; H, 6.0. $C_{26}H_{34}O_{10}S_2$ requires C, 54.7; H, 6.0%); $[\alpha]^{20}$ 24.5° (0.5, $CHCl_3$); δ_H ($CDCl_3$; 300 MHz) 7.80, 7.36 (dd, dd, 4 H, Ar), 4.20 (br ABq, 2 H, H-2, -3, $J_{2,3}$ 10 Hz), 3.80 (br, s, 2 H, H-1, -1′), 2.48 (s, $ArCH_3$), 1.28, and 1.19 [s, s, $C(CH_3)_2$]; δ_C ($CDCl_3$; 22.63 Hz) 114.8, 133.1, 129.8, 128.0 (Ar), 101.2 [$(CH_3)_2$], 69.3, 67.9, 67.3 (C-1, -2, -3), 24.3, 23.4 [$(CH_3)_2$], and 21.6 ($ArCH_3$) p.p.m.

Preparation of R,R-4,4′-*Bi*-(2,2-*dimethyl*-5-*hydroxymethyldioxolanyl*) *and its Bistoluene*-p-*sulphonate*.—The second set of fractions from chromatography above was combined and concentrated *in vacuo* to give *R*,*R*-4,4′-bi-(2,2-dimethyl-5-benzoyloxymethyldioxolanyl) (0.468 g) as an oil, δ_H (300 MHz; $CDCl_3$) 4.2 (br, m, 2αH-1, -2, -3), 3.71 (close coupled ABq, 2 H, H-1, -1′), 1.51 and 1.38 (s, s, 6 H, CH_3).

This was debenzoylated with NaOMe–MeOH as described above, diester (0.184 g) giving rise to diol (0.068 g, 68%) as an oil, δ_H (300 MHz; $CDCl_3$) 4.2 (br, m, 3 H, H-1, -1′, -2), 3.71 (d, H-3, $J_{2,3}$ 5 Hz) and 1.51; δ_C (22.6 MHz; $CDCl_3$) 109.0 (C-2), 77.4, 74.4 (C-4, -5), 61.6 (CH_2O), 27.3, 25.4 (CH_3), and 21.38 (s, s, 6 H, CH_3) p.p.m. Conversion into the bistoluene-*p*-sulphonate as described above gave R,R-4,4′-*bi*-(2,2-*dimethyl*-5-p-*tolylsulphonylmethyldioxolanyl*), m.p. 92—94 °C (Found: C, 54.7; H, 6.0. $C_{26}H_{34}O_{10}S_2$ requires C, 54.7; H, 6.0%); $[\alpha]^{20}$ −20.4° (1.5, $CHCl_3$); δ_H ($CDCl_3$; 300 MHz) 7.77, 7.32 (dd, dd, 4 H, Ar), 4.28—4.12 (s, 3 H, H-1, -2, -3), 3.94 (dd, 1 H, H-1′; $J_{1,1'}$ 11.5, $J_{1,2}$ 6.5 Hz), 2.40 (s, 3 H, $ArCH_3$), 1.33 [s, s, 6 H, $C(CH_3)_2$]; δ_C ($CDCl_3$; 22.63 MHz) 145.1, 132.4, 120.0, 128.2 (Ar), 109.5 [$(CH_3)_2$], 74.4, 74.0, 68.1 (C-1, -2, -3), 26.9, 25.2 [$C(CH_3)_2$], and 21.5 ($ArCH_3$) p.p.m.

Preparations of 4S,8S,9S,10S-2,2′,6,6′-*Tetramethyl*-4,8-*di*-[*bis*(*diphenylphosphino*)*methyl*]-1,3,5,7-*tetraoxadecalin and* S,S-4,4′-*Bis*-[2,2′-*dimethyl*-5-(*diphenylphosphinomethyl*)-*dioxolanyl*].—Numerous attempts were made to prepare biphosphines from the two mannitol-derived bistoluene-*p*-sulphonates employing $KPPh_2$ (from KH and $HPPh_2$–thf), but these led to impure products. A more successful alternative involving the corresponding methanesulphonates was therefore developed, which avoided the chromatographic separation. The crude dibenzoylacetonide, prepared directly from 1,6-dibenzoylmannitol, was de-esterified with MeONa–MeOH, giving a mixture of diols (3.3 g). This was dissolved in pyridine (50 ml) and cooled to 0 °C. Methanesulphonyl chloride (2.5 ml) was added and the mixture warmed to room temperature and stirred for 4 h. It was then poured into water (300 ml) and left at 5 °C overnight. The solid product was filtered, dried, and crystallised from hot MeOH. First was obtained 4S,8S,9S,10S-2,2′,6,6′-*tetramethyl*-4,8-*bis*(*methylsulphonyloxymethyl*)-1,3,5,7-*tetraoxadecalin* (1.53 g, 58% in this step) (Found: C, 40.2; H, 6.3; S, 14.9. $C_{14}H_{26}O_{10}S_2$ requires C, 40.2; H, 6.3; S, 15.3%). From the crystallisation residues the unstable isomeric S,S-4,4′-*bi*-[2,2-*dimethyl*-5-(*methylsulphonyloxymethyl*)*dioxolanyl*] was isolated (0.85 g, 32% in this step) (Found: C, 40.3; H, 6.4; S, 15.45. $C_{14}H_{26}O_{10}S_2$ requires C, 40.2; H, 6.2; S, 15.3%).

Diphenylphosphine (1.45 ml, 8.33 mmol) was dissolved in dry degassed diethyl ether under argon and n-butyl-lithium (6.27 ml, 1.55M in hexane) added by syringe. The yellow solution thus obtained was reduced in volume to *ca.* 3 ml, cooled to −78 °C and the yellow precipitate thus obtained washed three times with diethyl ether at −78 °C and dried *in vacuo*. Tetrahydrofuran (10 ml) was added at −78 °C, giving a clear red solution, followed by 4*R*,8R,9*R*,10*R*-2,2′,6,6′-tetramethyl-4,8-bis(methylsulphonyloxymethyl)-1,3,5,7-tetraoxadecalin (1.45 g, 3.47 mmol). The solution was stirred slowly, allowed to warm to room temperature, when an orange suspension resulted which slowly turned light yellow over 40 min at room temperature. The suspension was filtered through Celite, washed with tetrahydrofuran (4 × 3 ml), and the combined solvents were then removed *in vacuo*. The resulting light yellow oil was dissolved in hot MeOH and cooled to −78 °C overnight. The crystalline product was filtered and dried *in vacuo* giving 4S,-8S,9S,10S-2,2′,6,6′-*tetramethyl*-4,8-*di*[*bis*(*diphenylphosphino*)-*methyl*]-1,3,5,7-*tetraoxadecalin* (1.58 g, 76%), m.p. 125 °C (Found: C, 71.9; H, 6.6. $C_{36}H_{40}O_4P_2$ requires C, 72.2; H, 6.7%); δ_P (36.4 Hz; CH_3OH) −21.6 p.p.m; δ_H ($CDCl_3$; 300 MHz) 7.4 (m, 10 H, Ar), 3.75 (m, 2 H, H-2, -3), 2.48 (dt, 1 H, H-1, $J_{1,2} = J_{1,P}$ 2.5, $J_{1,1'}$ 14 Hz), 2.27 (ddd, 1 H, H-1′, $J_{1',P}$ 2, $J_{1',2}$ 6 Hz), 1.21, and 1.18 (s, s, CH_3); δ_C ($CDCl_3$; 22.63 MHz) 139.1, 132.1, 132.3, 127.6 (Ar, diastereotopic and P-coupled), 100.7 [$C(CH_3)_2$], 73.4 (C-3, J_{CP} 14 Hz), 67.7 (C-2, J_{CP} 24 Hz), 32.4 (C-3, J_{CP} 24 Hz), 24.4, and 23.7 [$C(CH_3)_2$] p.p.m.

Potassium hydride (0.03 g, 7.5 mmol) was suspended in tetrahydrofuran (15 ml) and $HPPh_2$ (0.67 ml, 3.86 mmol) slowly added by syringe. The red solution was stirred under argon for 1.5 h. A separate solution of *R*,*R*-4,4′-bi-(2,2-dimethyl-5-*p*-tolylsulphonyloxymethyldioxolanyl) (1.00 g, 1.75 mmol) in tetrahydrofuran (15 ml) was transferred slowly to the stirred phosphide solution under positive argon pressure, and the mixture was then left for 10 h. It was then hydrolysed by addition of H_2O (2 ml), solvent was removed *in vacuo*, and the residue was extracted into degassed CH_2Cl_2 and washed three times with brine. The solution was dried (K_2CO_3) and solvent removed *in vacuo* to leave a pale yellow viscous oil (0.836 g) which resisted attempts at crystallisation. This sample of *S*,*S*-4,4′-bi-[2,2-dimethyl-5-bis(diphenylphosphino)methyl-dioxolanyl] was contaminated with traces of $HPPh_2$, δ_P (36.4 MHz; CH_3OH) −20.9 p.p.m.; δ_H (CD_3OD; 300 MHz) 7.40 (br, m, Ar, 10 H) 4.25 (br, m, H-2, -3) 2.51 (ddd, H-1, $J_{1,1'}$ 13, $J_{1,2}$ 5 Hz), 2.27 (ddd, H-1′, $J_{1',2}$ 8 Hz), 1.42, and 1.26 (s, s, 6 H, CH_3). A portion was allowed to react with 2 equiv. methyl iodide, giving a crystalline methiodide, purified by recrystallisation from CH_2Cl_2–pentane, m.p. 300 °C (decomp) (Found: C, 50.6; H, 5.0. $C_{38}H_{46}I_2O_4P_2{\cdot}CH_2Cl_2$ requires C, 50.7; H, 5.15%).

Preparation of 4S,8R,9R,10S-2,2′,6,6′-*Tetramethyl*-4,8-*bis*-(p-*tolylsulphonyloxymethyl*)-1,3,5,7-*tetraoxadecalin*.—L-Iditol hexa-acetate (17.3 g, 40 mmol) was suspended in dry MeOH and a methanolic solution of NaOMe (50 ml, 0.085M) added in one portion. The mixture was stirred overnight, methanol was evaporated *in vacuo*, and the remaining syrup was evacuated at 0.1 mmHg for 2 days. The resulting L-iditol was used as prepared. It was suspended in dry pyridine (70 ml) to which molecular sieves (4A, freshly activated) were added, and stirred for 1 h. After cooling to 0 °C, benzoyl chloride (15.2 g, 0.108 mmol) was added, the mixture allowed to warm to room temperature, and stirred in a dry atmosphere for 6 h. It was poured into water (350 ml) and extracted with CH_2Cl_2 (5 × 150 ml). The aqueous layer was quickly washed with dilute HCl (1M; 4 × 100 ml) and

then with saturated Na_2CO_3. Solvent was removed *in vacuo* and evacuation continued overnight giving crude 1,6-dibenzoyl-L-iditol which was used directly (13.5 g). It was suspended in 2,2-dimethoxypropane (100 ml) and toluene-*p*-sulphonic acid (0.15 g) added. The mixture was stirred for 45 h, Na_2CO_3 added to neutralise excess of acid, and solvent removed to leave an oil (*ca.* 15 g). Examination by n.m.r. demonstrated that the desired dioxolanes had been formed. To this oil (1.35 g, *ca.* 5.15 mmol) in pyridine (40 ml) was added toluene-*p*-sulphonyl chloride (2.95 g, 15.5 mmol) with stirring, the temperature being maintained at 5 °C. Stirring was continued for 16 h and then the mixture was poured into H_2O (250 ml) and maintained at 0 °C for 72 h. The yellowish precipitate (2.23 g) was recrystallised from methanol at −30 °C to yield a mixture of bistoluene-*p*-sulphonates (1.058 g) which was further recrystallised using the vapour diffusion technique between $CHCl_3$ and diethyl ether. There was thus obtained first 4S,8R,9R,10S-2,2′,6,6′-*tetramethyl*-4,8-*bis*-(p-*tolylsulphonyloxymethyl*)-1,3,5,7-*tetraoxadecalin* as a fine precipitate, m.p. 152—154 °C (Found, C, 54.4; H, 5.9; S, 11.3. $C_{26}H_{34}O_{10}S_2$ requires C, 54.7; H, 6.0; S, 11.2%); δ_H ($CDCl_3$; 300 MHz) 7.81, 7.35 (d, d, Ar), 4.15, 4.00 (br, m, H-1, -1′, -2), 3.65 (br, s, H-3), 2.47 ($ArCH_3$), 1.32, and 1.25 [$C(CH_3)_2$]; δ_C ($CDCl_3$; 22.63 MHz) 144.9, 132.9, 129.0 (Ar), 98.8 [$C(CH_3)_2$], 68.7, 67.8, 61.7 (C-1, -2, -3), 29.04, 18.9 [$C(CH_3)_2$], and 21.6 ($ArCH_3$) p.p.m.

Preparation of 4R,8S,9R,10S-2,2′,6,6′-*Tetramethyl*-4,8-*bis*-(*diphenylphosphinomethyl*)-1,3,5,7-*tetraoxadecalin*.—To a suspension of dry potassium hydride (0.140 g, 3.5mM) in tetrahydrofuran (3 ml) was added diphenylphosphine (0.48 l; 1.4mM) and the resulting red suspension stirred at room temperature for 1 h. The above tosylate (0.312 g, 0.55 mmol) was then introduced and the mixture stirred at room temperature for 17 h under argon. Solvent was then removed *in vacuo* and slightly wet, degassed ethanol added (15 ml) so that the red oil became colourless. A precipitate was formed which remained on warming to 60 °C. The supernatant liquid was filtered under argon and the solid washed with warm ethanol (2 × 5 ml). It was dissolved in the minimum quantity of degassed dichloromethane and recrystallised at −78 °C by addition of degassed ethanol. There was thus obtained 4R,8S,9S,10R-2,2′,6,6′-*tetramethyl*-4,8-*bis*(*diphenylphosphinomethyl*)-1,3,5,7-*tetraoxadecalin* (0.055 g), m.p. 154—159 °C (Found: C, 72.35; H, 6.45. $C_{36}H_{40}O_4P_2$ requires C, 72.2; H, 6.7%); δ_H (CH_2Cl_2; 300 MHz) 7.58 (br, m, Ar), 4.00 (q, 1 H, H-2), 3.58 (s, 1 H, H-3), 2.38 (d, ABq, 2 H, H-1, -1′), 1.38 and 1.17 (s, s, 6 H, CH_3).

Preparation of S,R-4,4′-*Bis*-[2,2′-*dimethyl*-5-(p-*tolylsulphonyloxymethyl*)*dioxolanyl*].—The filtrate from fractional crystallisation of L-iditol-derived tosylates was further subjected to the vapour diffusion crystallisation technique and deposited a precipitate of *fluffy needles*, m.p. 124—125 °C (Found; C, 54.7; H, 5.9: S, 11.1. $C_{26}H_{34}O_{10}S_2$ requires C, 54.7; H, 6.0; S 11.2%); δ_H ($CDCl_3$; 300 MHz) 7.83, 7.38 (s, s, Ar, 4 H), 4.15 (m, 3 H, H-1, -2), 3.88 (d, 1 H, H-3, $J_{2,3}$ 7 Hz), 2.45 (s, 3 H, $ArCH_3$), 1.31, and 1.32 [s, s, 6 H, $C(CH_3)_2$]; δ_C ($CDCl_3$; 22.63 MHz) 145.1, 132.7, 129.9, 128.0 (Ar), 110.5 [$C(CH_3)_2$], 75.6, 74.6, 68.7 (CHO), 26.9, 26.6 [$C(CH_3)_2$], and 21.6 ($ArCH_3$) p.p.m.

Preparation of S,R-4,4′-*Bi*-(2,2′-*dimethyl*-5-*diphenylphosphinomethyl*)*dioxolanyl*].—To a suspension of dry potassium hydride (0.302 g, 7.55 mmol) in tetrahydrofuran (5 ml) was added diphenylphosphine (0.680 ml, 3.91 mmol) and the suspension stirred under argon for 1.5 h. The above tosylate (0.905 g, 1.6 mmol) was then added in one portion and the mixture stirred under argon for 17 h. Solvent was removed *in vacuo* and the residue extracted into dichloromethane (10 ml) which was then washed with water (2 × 5 ml) and isolated by solvent removal. The residue was purified by extraction into hot ethanol, cooling, and filtration. There was thus obtained *S,R*-4,4′-bi-(2,2′-dimethyl-5-diphenylphosphinomethyl)dioxolanyl] (0.524 g, 56%), m.p. 104—107 °C (Found: C, 72.0; H, 6.6. $C_{36}H_{40}O_2P_4$ requires C, 72.2; H, 6.7%), δ_H ($CDCl_3$; 300 MHz) 7.44 (2 H, *o*-Ar), 7.32 (3 H, *m,p*-Ar), 4.20 (m, 1 H, H-2, $J_{1,2}$ 6, $J_{2,3}$ 7.5, $J_{2,P}$ 6 Hz), 3.89 (d, 1 H, H-3), 2.32 (d, ABq, 2 H, H-1, -1′), 1.33, and 1.28 (s, s, CH_3), δ_C (CD_2Cl_2; 22.63 MHz) 133.2 (*o*-Ar, 2 Hz diastereotopic splitting, $J_{C,P}$ 19 Hz), 128.9 (*m,p*-Ar), 109.3 [$C(CH_3)_2$], 80.0 (C-3), 75.4 (C-2, J_{CP} 16 Hz), 32.5 (C-1, J_{CP} 16 Hz), 27.5, and 26.6 (CH_3) p.p.m.

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