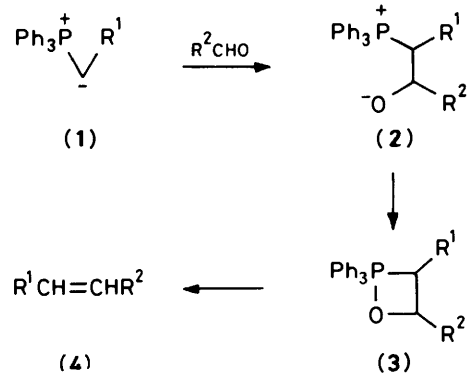
The Stereocontrolled Horner-Wittig Reaction: Synthesis of Disubstituted Alkenes

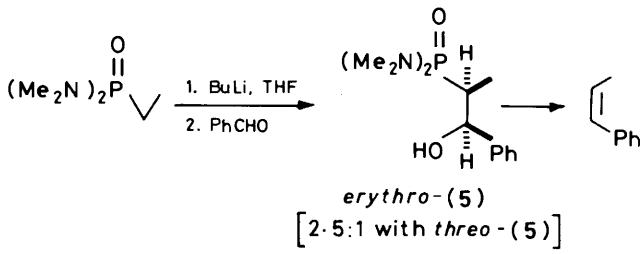
Antony D. Buss and Stuart Warren *
University Chemical Laboratories, Lensfield Road, Cambridge CB2 1EW

Addition of the lithium derivatives of phosphine oxides $Ph_2P(O)CH_2R^1$ to aldehydes gives *erythro* adducts (**11**) with good stereoselectivity. Reduction of α-diphenylphosphinoyl ketones (**12**) gives *threo* adducts (**11**) with even better stereoselectivity. Purification by flash chromatography and/or crystallisation followed by elimination of Ph_2PO_2) gives pure *Z*- or *E*-alkenes with high material conversion. Explanations are offered for the stereoselectivities, conditions defined for full stereochemical control, and guidelines suggested for approaches to a given alkene.

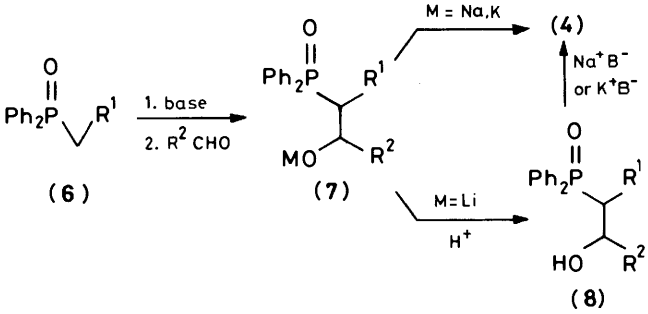
The Wittig olefin synthesis is chemoselective, regiospecific, and connective and is a cornerstone of laboratory [1] and industrial [2] practice. It can also be stereoselective [3] in that a given ylide (**1**) reacts with a given aldehyde to give good yields of predominantly one isomer,[4] *E* or *Z*, but it lacks full stereochemical control. Conditions can be adjusted to change the *E*:*Z* ratio, particularly to get predominantly *E*-product (**4**) from a simple alkyl ylide by Schlosser's modification.[5] Even so, mixtures of alkenes are produced and separation from each other and from triphenylphosphine oxide can be difficult. This can be an advantage where *e.g.* an insect pheromone is an *E,Z* mixture,[6] but even in this field,[7] methods with full stereochemical control such as reduction of acetylenes [8] or use of vinyl metal reagents [9] (also usually made from acetylenes) have been preferred. These methods allow pure *E*- or pure *Z*-alkene to be prepared from essentially the same starting materials in high yield and a Wittig style reaction with these characteristics would be very valuable.



The stereoselectivity of the Wittig reaction is determined at the formation of the betaine (**2**) since the formation and decomposition of the oxaphosphetane (**3**) are stereospecific. In principle, a single diastereoisomer of the betaine (**2**) (if the reaction could be stopped at this stage or made totally stereoselective) would give a single geometrical isomer of the product: *E*-(**4**) from *threo*-(**2**) and *Z*-(**4**) from *erythro*-(**2**). In practice, this is doubtful as the formation of the betaine (**2**) from the ylide (**1**) is often reversible. We report [10] a version of the Horner-Wittig reaction using the diphenylphosphinoyl (Ph_2PO) group in phosphine oxides (**6**) which allows: (*a*) 80—90% stereoselective syntheses in good yield of either *erythro* or *threo* intermediates from essentially the same starting materials; (*b*) simple purification of either stable crystalline intermediate; (*c*) nearly 100% stereospecific elimination of $Ph_2PO_2^-$ from either; and (*d*) crossing from *Z*-selective to *E*-selective pathways by a redox sequence.



The nearest approach to such a stereocontrolled Wittig process was Corey's phosphonamide variant [11] where crystallisation of the adduct (**5**) at −20 °C gave pure *erythro*-(**5**) which gave pure *Z*-1-phenylpropene on elimination. The *threo* isomer (**17**) was formed stereoselectively by reduction of the ketone (**16**). Later experiments [12] revealed problems in a wider application of this approach and it has not proved popular.



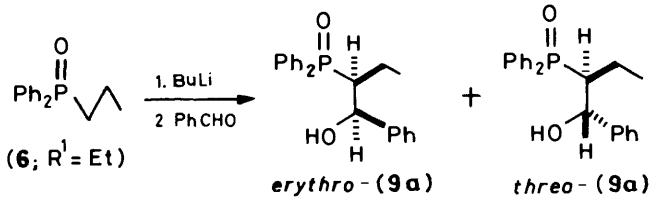
Horner [13] originally used phosphine oxides (**6**) in a one-step olefin synthesis with $KOBu^t$ as base. His only disubstituted olefin products were diarylethylenes whose sharp m.p.s indicated all *E*-geometry. This was almost certainly a result of the reversibility of the formation of adduct (**7**; M = K) when R^1 is aryl.[14] Horner also reported [13] that when PhLi was used as base, the intermediate (**7**; M = Li) was stable to the reaction conditions and the β-hydroxyalkylphosphine oxides (**8**) were the products. Exchanging Li for Na or K completed the reaction. Isolation and purification of single diastereoisomers of the alcohol (**8**) could have provided a stereocontrolled olefin synthesis, but Horner's only attempt [15] involved the benzyl-

phosphine oxide adduct (**8**; $R^1 = R^2 = Ph$) which we now know[14] to have been an unfortunate choice.

Whitham's olefin inversion[16] and our synthesis of single geometrical isomers of dienes[17–19] established the stereochemical stability of the intermediates (**7**; M = Li, $R^1 \neq Ar$) and the stereospecificity of the elimination [(**8**) to (**4**)]. This reaction occurs with retention of configuration at phosphorus[20] and is a *syn*-elimination[21] so that *erythro*-(**8**) gives *Z*-(**4**) and *threo*-(**8**) gives *E*-(**4**). Eclipsed R^1 and R^2 groups in the cyclisation of *erythro*-(**8**) slow down this reaction,[14] and reports[4,22] of Horner-Wittig reactions giving low yields of *trans*-products are probably the result of the faster elimination of the *threo*-isomer, used by Pattenden[23] to make all *E*-polyenes. Phosphine oxides with anion-stabilising substituents (**6**; R^1 = SPh,[24] CN[25]) give one step *trans*-selective olefination in high yields, because of the reversibility of the formation of intermediate (**7**) and the ease of elimination,[24] even when M = Li. Conditions have been adjusted to produce 1:1 *E*:*Z* mixtures corresponding to natural pheromones.[26]

We had used[27] the α-methoxyphosphine oxide (**6**; R^1 = OMe) to make single geometrical isomers of vinyl ethers but observed almost no stereoselectivity in the formation of adducts (**8**; R^1 = OMe) and some difficulties in the separation of the diastereoisomers. We therefore set out to find different sets of conditions which would give high stereoselectivity in the formation of *erythro*- and *threo*-adducts (**8**), practical methods of separation and purification, and conditions for stereospecific elimination so that single geometrical isomers of simple alkenes could be prepared without *E*/*Z* isomer separation. We first found conditions to enhance the natural stereoselectivity of the Horner-Wittig reaction in favour of *erythro*-(**8**) and then used an alternative route to *threo*-(**8**).

Z-Alkene Synthesis via erythro-(**11**).—In our preliminary experiments we used n-butyl-lithium (BuLi) as base on propyldiphenylphosphine oxide (**6**; R^1 = Et) with benzaldehyde as electrophile. The diastereoisomers were easily separated by flash column chromatography[28] on silica using EtOAc, and then Me_2CO as eluants. This technique allowed rapid separation of gram quantities with high recovery (typically 90%) of material. *erythro*-(**9a**) and *threo*-(**9b**) Adducts were easily distinguished as their n.m.r. spectra had been correlated[21] with an *X*-ray crystal structure of *erythro*-(1*RS*, 2*SR*)-(**8**; R^1 = Me, R^2 = Ph).



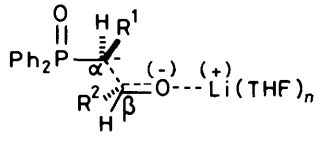
Solvent Effects.—The Wittig reaction with 'reactive' ylides (**1**; R^1 = alkyl) favours *Z*-products (**4**) but is very sensitive to solvent. In dipolar aprotic solvents and in salt-free solutions in non-polar solvents (including ethers) the *Z* isomer is particularly favoured.[3] We needed lithium salts to be present to stop the Horner-Wittig reaction at adducts (**7**; M = Li) and BuLi cannot be used in dipolar aprotic solvents. In hydrocarbon solvents (Table 1) there was indeed very little stereoselectivity in the formation of adduct (**9**) and ether gave little improvement. However, dimethoxyethane (DME) and tetrahydrofuran (THF) gave high stereoselectivity, over 85% *erythro*-(**9a**) being formed. These solvents complex lithium and addition of $Me_2NCH_2CH_2NMe_2$ (TMEDA) or 1,3-dimethylimidazolidine[29] (DMI) in THF improved the stereoselectivity to 88:12. An improvement in yield and stereoselectivity (from 65:35 to 83:17 in favour of *erythro*) occurs[14] in the addition of Ph_2POCH_2Ph to benzaldehyde using BuLi in THF when the solvent is saturated with LiI. All these experiments were carried out at −78 °C (see next section and Table 2).

Table 1. Solvent effect on the stereoselectivity of formation of adducts (**9**)

Entry	Solvent	Ratio[a] (9a):(b)
1	Pentane	55 45
2	Toluene	58 42
3	Ether	60 40
4	Dimethoxyethane	84 16
5	THF	85 15
6	THF + TMEDA[b]	88 12
7	THF + DMI[c]	88 12

[a] Measured by n.m.r. analysis of the methyl signals δ 0.3—0.8. [b] One equivalent based on phosphine oxide (**6**; R^1 = Et). [c] Two equivalents based on phosphine oxide (**6**; R^1 = Et).

We know that the lithium atom must bind to the developing anion in (**7**; M = Li) and these results suggest that the stereoselectivity arises because the complexed OLi group, as the largest substituent on C-β (**10**), prefers to be antiperiplanar to Ph_2PO, the largest group on C-α (**10**), and that R^1 and R^2 then also prefer to be *anti* in the transition state (**10**) leading to the *erythro*-isomer. In hydrocarbon solvents, the uncomplexed OLi group is of the same order of size as R^2.



(**10**)

In an attempt to achieve a Schlosser-like[5] inversion to the *threo*-series, the 88:12 mixture of intermediates (**7**; R^1 = Et, R^2 = Ph, M = Li) in THF was treated with two further equivalents of BuLi. The ratio quickly changed to 69:31 but no further change occurred even after 48 h at room temperature. The 69:31 (*erythro*:*threo*) is presumably an equilibrium composition under the reaction conditions, the transition state (**10**) being more sensitive to steric effects than the intermediate (**7**; M = Li).

Effects of Temperature.—Lower temperatures enhanced *erythro*-selectivity. All these experiments were carried out in THF (see previous section and Table 1). Even at +10 °C (Table 2) the *erythro*-isomer is favoured, but only by *ca.* 2:1. At −78 °C this becomes a practically useful 6:1, and more than 11:1 at −100 °C. The extra effort needed to get to −100 °C did not seem worthwhile except for branched chain alkylphosphine oxides (Table 2, entries 4,5) where a 2:1 selectivity at −78 °C became a useful 5:1 at the lower temperature. Flash column chromatography separates either of these ratios, but 5—6:1 means more than 70% pure *erythro*-isomer isolated.

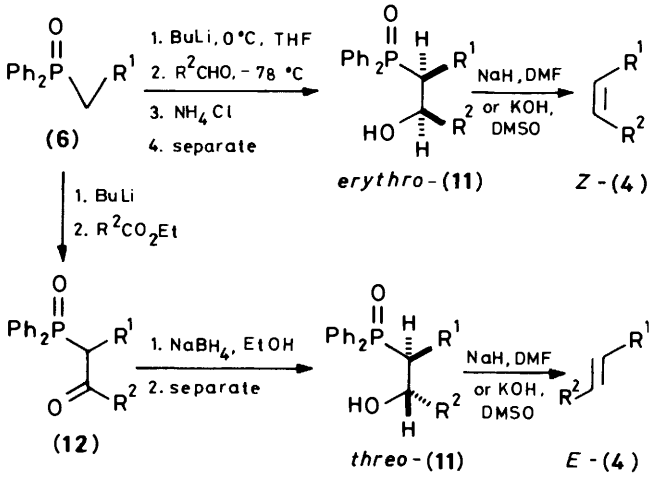
In general we used BuLi in THF at 0 °C to generate the lithium derivative of the phosphine oxides (**6**). This was cooled to −78 °C and the aldehyde added at that temperature. The critical stage was then over as quenching with water to give adduct (**9**) after 5 min at −78 °C or after 4 days at 25 °C gave

Table 2. Temperature effects on the formation of adducts (**11**) in THF

Entry	Compound R^1	Compound R^2	Temp. (°C)	Ratio[a] *erythro*	Ratio[a] *threo*
1	Et	Ph	+10	66	34
2	Et	Ph	−78	85	15
3	Et	Ph	−100	92	8
4	Pr^i	Ph	−78	64	36
5	Pr^i	Ph	−100	83	17

[a] Determined by analysis of the n.m.r. signals of the methyl groups δ 1.3—0.3.

the same stereoselectivity. Only adducts of $Ph_2P(O)CH_2Ph$, like those of (**6**; R^1 = SPh),[30] must be quenched below −50 °C or the elimination stage occurs spontaneously.



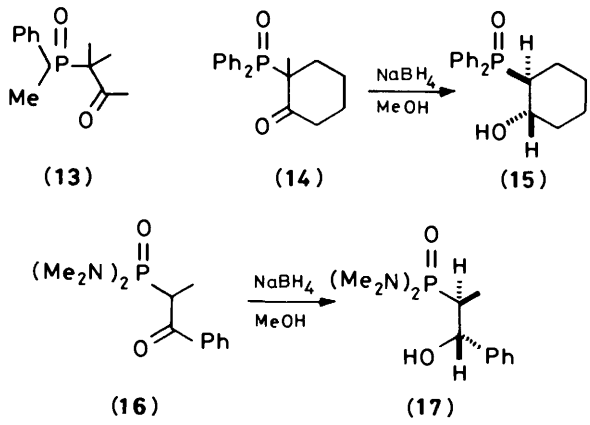
Substituent Effects.—The simplest case (**11a**; $R^1 = R^2$ = Me) gives a 3:1 selectivity in favour of *erythro*-(**11a**) and we have systematically varied the size and shape of both R^1 and R^2 (Table 3) to assess the effect of steric and electronic factors on this stereoselectivity. The series of benzaldehyde adducts (**11b—g**) and *p*-methoxybenzaldehyde adducts (**11j—n,q**) show that variation of a simple alkyl group as R^1 maintains a selectivity of *ca.* 6:1 unless R^1 is branched, and even then there is a marked decline only if the branch point is the next atom in the chain (**11g,q**). This suggests that, providing R^1 is smaller than Ph_2PO, a reasonably large R^2 favours transition state (**10**).

With R^1 = Me and varying R^2 from Me (**11a**) to Ph (**11b**) and substituted phenyl (**11h—j,r**) suggests that a larger R^2 is an advantage. If solvated OLi is very large indeed, as we surmise, then a large R^2 emphasises the interaction between R^1 and R^2 in the transition state (**10**). The series with R^1 = Ph (**11u—w,y**) and R^1 = *p*-methoxyphenyl (**11x**) suggest that stereoselectivity is insensitive to the size of R^2 when R^1 is aromatic, and the series (**11a,b,h,i,j,r,s**) suggests that it is relatively insensitive to R^2 when R^1 is methyl.

One substituent, cyclohexyl as R^1 or R^2 (**11s,taa**) gave us our only examples with no stereoselectivity at all. This is the largest substituent we examined and it is possible that it can compete in size with Ph_2PO on the one atom and solvated OLi on the other. Only two compounds (**11o**) and (**11aa**) could not be separated by flash chromatography.

E-Alkene Synthesis via threo-(**11**).—Horner-Wittig intermediates are stable compounds and can be made by any normal alcohol synthesis and not necessarily by the addition of phosphine oxide anions to aldehydes, thus Whitham's olefin inversion[16] uses the opening of epoxides with Ph_2PLi. We were unable to find conditions for the Horner-Wittig reaction which gave *threo*-(**11**) as the major product so we turned to the reduction of the ketones[31] (**12**). We had made these ketones[21,32] by acylation of the lithium derivatives of phosphine oxides with esters or the copper derivatives with acid chlorides or by the oxidation of the adducts (**11**) with a variety of oxidising agents.[21]

Horner[15] had reduced the ketone (**12**; $R^1 = R^2$ = Ph) with hydrogen over palladium and isolated 70% *threo*- and 10% *erythro*-(**11y**). We had observed[33] poor 1,3-diastereoselectivity (phosphorus is the second chiral centre) in the reduction of ketone (**13**) with sodium borohydride but high (*ca.* 90:10) stereoselectivity with $Li(Bu^tO)_3AlH$. On the other hand, cyclic ketone (**14**) gave very high stereoselectivity with $NaBH_4$ in methanol, 98% of *threo*-alcohol (**15**) being isolated.[34] Corey[11] similarly isolated an 80% yield of a 98% *threo*-alcohol (**17**) from the reduction of phosphonamide (**16**) with $NaBH_4$ in methanol.



Choice of Reducing Agents (*Table 4*).—Reduction of the α-diphenylphosphinoyl ketone (**12**; R^1 = Me, R^2 = Ph) with a variety of reducing agents showed that these ketones are poorly reduced by hydrogenation or hindered hydrides (entries 1 and 2, Table 4), though stereoselectivity was very high in both cases. More powerful reducing agents (borane or $LiAlH_4$) gave good yields of alcohol but poor stereoselectivity. The best compromise was with $NaBH_4$ in ethanol which gave quantitative reduction and high (89:11) stereoselectivity. We normally used $NaBH_4$ in ethanol or methanol.

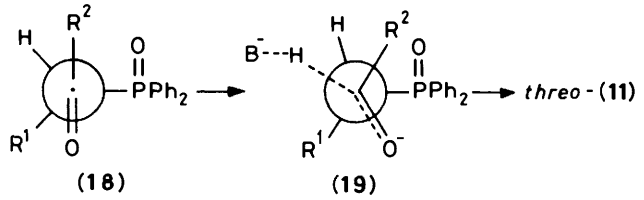
Effect of Substituents.—In general, *threo*-selectivity from reduction of the ketones (**12**) was greater than *erythro*-selectivity from the addition of aldehydes to phosphine oxide anions, and less susceptible to substituent effects. With R^2 = Ph, variation of R^1 (Table 5) produced almost no change in the *threo*-selectivity, even when $R^1 = Pr^i$ (**11g**). With R^1 = Me, increasing the size of R^2 slightly increased *threo*-selectivity (**11a,b,j,r,s,bb**) so that *ca.* 80—90% pure *threo*-alcohol (**11**) could be isolated in most cases.

We have observed[35] a similar *threo*-selectivity and similar substituent effects in the reduction of α-phenylthio ketones. The *threo*-selectivity of all these reductions fits Cram's rule but the substituent effects fit Felkin's model[36] of the transition state (**19**) better. The largest group (Ph_2PO or PhS) on the α-carbon atom sits at right angles to the carbonyl group for steric reasons.

Table 3.

Adduct	R^1	R^2	Yield (%)[a] (11)	*erythro* : *threo*	Yield *erythro* isolated	Yield (%) *Z*-(4)	%*E* by g.l.c.	Yield (%) *threo* isolated	Yield (%) *E*-(4)	%*Z* by g.l.c.
(11a)	Me	Me	93	75:25	69	—	—	23	—	—
(11b)	Me	Ph	88	88:12	78	75	5	11	81	0
(11c)	Et	Ph	86	85:15	73	79	0	13	89	0
(11d)	Pr	Ph	94	85:15	80	80	2	14	92	0
(11e)	Bu	Ph	84	84:16	71	85	4	14	91	0
(11f)	Bu^i	Ph	81	80:20	65	86	3	16	95	1
(11g)	Pr^i	Ph	85	64:36	54	78	0	31	85	0
(11h)	Me	2-$MeOC_6H_4$	91	81:19	74	83	2	18	90	3
(11i)	Me	3-$MeOC_6H_4$	86	80:20	69	85	5	17	88	0
(11j)	Me	4-$MeOC_6H_4$	92	87:13	81	75	6	12	81	0
(11k)	Et	4-$MeOC_6H_4$	*b*	86:14	—	—	—	—	—	—
(11l)	Pr	4-$MeOC_6H_4$	*b*	86:14	—	—	—	—	—	—
(11m)	Bu	4-$MeOC_6H_4$	*b*	83:17	—	—	—	—	—	—
(11n)	Bu^i	4-$MeOC_6H_4$	*b*	80:20	—	—	—	—	—	—
(11o)	Pr^i	2-$MeOC_6H_4$	*b*	67:33	*c*	—	—	*c*	—	—
(11p)	Pr^i	3-$MeOC_6H_4$	85	66:34	56	74	3	29	89	0
(11q)	Pr^i	4-$MeOC_6H_4$	90	70:30	63	70	3	27	80	0
(11r)	Me	*d*	83	90:10	76	84	4	8	86	0
(11s)	Me	C_6H_{11}[e]	86	79:21	69	79	0	18	80	0
(11t)	R[f]	C_6H_{11}[e]	*g*	50:50	—	—	—	—	—	—
(11u)	Ph	Me	97	72:28	70	78	50	27	86	0
(11v)	Ph	Pr^n	93	67:33	62	72	67	31	94	0
(11w)	Ph	Bu^i	67	71:29	48	81	87	20	85	0
(11x)	4-$MeOC_6H_4$	R[h]	*g*	67:33	—	—	—	—	—	—
(11y)	Ph	Ph	88	83:17[j]	20	61	5	10	95	0
(11z)	$PhCH_2CH_2$	Me	95	58:42	56	81	3	39	76	0.5
(11aa)	C_6H_{11}[e]	Me	87	50:50[b]	*c*	—	—	*c*	—	—

[a] Combined yield of separated diastereoisomers. [b] Ratio determined by n.m.r. [c] Diastereoisomers could not be separated by chromatography. [d] 3,4-Methylenedioxyphenyl. [e] Cyclohexyl. [f] R = Pr, Bu, Pr^i, Bu^i. [g] Ratio estimated by t.l.c. [h] R = Me, Et, Pr, Bu, Bu^i, Pr^i. [i] See ref. 14. [j] In the presence of LiI.



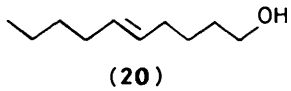
(18) (19)

Anh[37] suggests that the C bond with the lowest σ^* (C^α–P or C^α–S) would also prefer to sit at right angles to the carbonyl group for maximum interaction with the p orbitals. In α-diphenylphosphinoyl ketones these factors co-operate. The orientation of the remaining groups in (**18**) results from the larger groups R^1 and R^2 keeping as far apart as possible. A larger R^2 gives higher stereoselectivity (as with α-phenylthio ketones)[35] as it makes this factor more decisive. A larger R^1 will have little effect unless it rivals Ph_2PO in size.

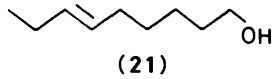
We have recently extended this work to the reduction of α-diphenylphosphinoyl ketones having hydroxy,[38] acetal,[39] or carboxyl[40] functionality in R^1 or R^2 (Table 6). Similar *threo*-selectivity is observed in every case and we have used this route to make unsaturated alcohols (**20**), (**21**), and (**22**), γ,δ-unsaturated acetals (**23**), and unsaturated acids (**24**) with *E* double bonds.

Completion of the Horner-Wittig Reaction.—The elimination of $Ph_2PO_2^-$ from adducts (**11**) is rapid if R^1 is conjugating (allylic,[18,19,23,41] aryl[14]) or electron-withdrawing (PhS,[24] CN[24]), but this may lead to loss of stereospecificity by the reversion of intermediate (**7**) to the starting materials.

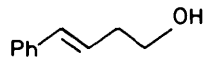
From a variety of conditions[21] we selected NaH in dimethylformamide (DMF) or KOH in dimethyl sulphoxide (DMSO) (both at 50 °C) as giving the highest yield with maximum stereospecificity. The examples in Tables 3 and 5 were carried out under these conditions and the stereospecificity of the reaction checked by g.l.c. analysis of the products. Essentially all the *threo*-adducts (**11**) gave *E* alkenes with total stereospecificity and in high yields. The *erythro*-adducts (**11**) with both R^1 and R^2 as alkyl groups gave pure *Z* alkenes. *erythro*-Adducts (**11**; R^2 = Ar) give high stereospecificity (usually <5% *E* alkene), but *erythro*-adducts (**11**; R^1 = Ar), that is adducts of benzylic phosphine oxides, gave poor stereospecificity and low yields, considerable amounts of starting materials $Ph_2P(O)CH_2Ar$ and R^2CHO being formed. Loss of stereospecificity results[14] from partial dissociation to starting materials during the slow elimination of the *erythro*-adducts (**11**).



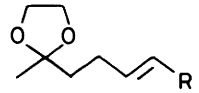
(20)



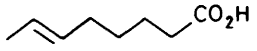
(21)



(22)



(23)



(24)

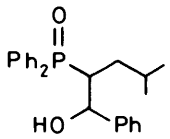
Thus the synthesis of *Z*-alkene (**25**) can be accomplished *via*

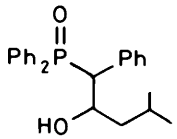
Table 4. Stereoselectivity of reduction of (12; R^1 = Me, R^2 = Ph) with different reducing agents

Entry	Method	Yield (%) (12)	Yield (%) (11)	*threo*: *erythro*
1	H_2, PtO_2, MeOH, 25 °C	50[a]	50[a]	100:0[a]
2	$Li(Bu^tO)_3AlH$, PhMe, 100 °C	60[a]	40[a]	>90:10[a]
3	$LiAlH_4$, THF, 0 °C	—	98	54:43
4	B_2H_6, THF, −78 °C	—	98	73:27
5	$NaBH_4$, EtOH	—	100	89:11

[a] By n.m.r.

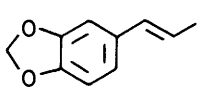
(**11f**) or (**11w**). The benzaldehyde adduct (**11f**) is formed in 81% yield (80:20 stereoselectivity) and 65% of *erythro*-(**11f**) can be isolated giving on elimination an 86% yield of *Z*-(**25**) containing 3% *E*-(**25**) by g.l.c. The benzyldiphenylphosphine oxide adduct (**11w**) is formed in 67% yield (71:29) stereoselectivity) and only 48% of *erythro*-(**11f**) can be isolated. Elimination gives 81% alkene, but this is 87% *E*-(**25**) by g.l.c. Other conditions gave lower yields of alkene and more starting materials (KH–DMF) or starting material alone (LiH–DMF or K_2CO_3–DMF). For every reason, therefore, aromatic groups should occupy the R^2 rather than the R^1 position in adducts (**11**).

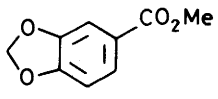

(**11f**)


(**11w**)


Z-(**25**)

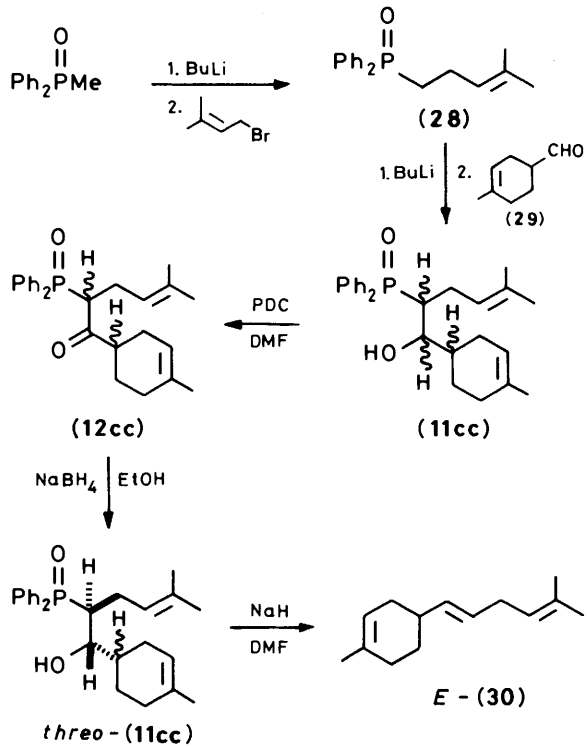
More generally, the larger of the two substituents on the double bond should occupy the R^2 position, whether *Z*- or *E*-alkene is wanted, as should any anion-stabilising or conjugating group. The exception to this rule is if mixtures (*e.g.* of vinyl sulphides for conversion into ketones[24]) are wanted when advantage may be taken of the faster elimination when R^1 is an anion-stabilising group.


E-(**26**)


(**27**)

The synthesis of both isomers of isosafrole (**26**) illustrates the approach. The Wittig reaction between Ph_3PEt^+ and piperonal gives an 87:13 mixture of *E*- and *Z*-isosafrole in 57% yield.[42] Our route from $Ph_2P(O)Et$ and piperonal gives *erythro*-(**11r**) in 76% yield (Table 3) and hence *Z*-isosafrole (**26**) in 84% yield (4% *E* by g.l.c.). Acylation of $Ph_2P(O)Et$ with the methyl ester (**27**) gave α-diphenylphosphinoyl ketone (**12r**) in 85% yield (Table 5), reduction gave *threo*-(**11r**) in 91% yield and hence *E*-isosafrole (**26**) in 86% yield. Overall yields from the phosphine oxide were: *Z*-isosafrole 68% and *E*-isosafrole 67%. Each isomer has been used by Büchi[43] in natural product synthesis.

Finally, the *E*-triene (**30**) was synthesized both to investigate the effect of a third chiral centre and to illustrate the oxidative approach to ketone (**12cc**) (Table 5). Prenylation of $Ph_2P(O)Me$ gave the homoallyl phosphine oxide (**28**) whose lithium derivative added to the Diels-Alder adduct (**29**) to give a mixture of diastereoisomers (three chiral centres) of adduct (**11cc**). Oxidation with PDC gave the ketone (**12cc**) which was reduced to another mixture of diastereoisomers in which one or both *threo*-alcohols (**11cc**) evidently predominated. Chromatography gave a single crystalline alcohol in 75% yield which gave pure *E*-triene (**30**) (98% yield) on elimination. It may be that the third chiral centre is controlled either in the addition or by epimerisation of the ketone or it may be that only the functionalised chiral centres affect the binding to silica and hence the chromatographic separation.



Experimental

Proton magnetic resonance spectra were recorded on a Bruker WH-400, Varian Associates HA 100, EM-390, EM-360A, CFT-20 or Hitachi–Perkin-Elmer R24A instrument. Tetramethylsilane was used as the internal standard with chemical shifts (δ) given in p.p.m. and signals marked with asterisk assigned to diastereotopic protons. I.r. spectra were recorded as Nujol mulls unless otherwise stated using a Perkin-Elmer 297, 257, or 157G grating spectrophotometer. Mass spectra were recorded on an A.E.I.–Kratos MS30 instrument. Gas-liquid chromatograms were obtained using a Perkin-Elmer F11 flame-ionisation instrument with the following columns: 1, 15% Carbowax 20M on Chromosorb W; 2, 15% Silicone grease PE 380, 12 ft × $\frac{1}{8}$ in; 3, WCOT CPWax 51, 2.5 m capillary column; 4, 15% LAC-2R-446 on Chromosorb W, 9 ft × $\frac{1}{8}$ in; 5, 20% DEGS, 2 m × $\frac{1}{8}$ in; 6, 3% OV-275, 2 m capillary column.

Thin-layer chromatograms were run on commercially prepared pre-coated plates (Merck, Kieselgel $60F_{254}$) and eluted with EtOAc unless otherwise stated. Flash column chromatography[28] was carried out using a 6 in × 2 in bed of Merck Kieselgel 60 (230—400 mesh) silica. Optimum separation of diastereoisomeric phosphine oxides was achieved by eluting with solvent which gave the midpoint between the isomers as *ca.* R_F 0.45 on t.l.c. High pressure liquid chromatography was

Table 5.

Compound	R^1	R^2	Yield (%) (12)	Yield (%)[a] (11)	*threo*: *erythro*	*threo*-(11) % isolated	Yield (%) *E*-(4)	%*Z* by g.l.c.	*erythro*-(11) % isolated
(11a)	Me	Me	—	—	83:17	—	—	–	—
(11b)	Me	Ph	66	100	89:11	89	81	0	11
(11c)	Et	Ph	65	99	89:11	88	89	0	11
(11d)	Pr	Ph	83	98	89:11	87	92	0	10
(11e)	Bu	Ph	81	91	89:11	81	91	0	10
(11f)	Bu^i	Ph	75	87	89:11	77	95	1	9
(11g)	Pr^i	Ph	69	91	83:17	75	85	0	15
(11j)	Me	4-$MeOC_6H_4$	79	99	90:10	89	81	0	19
(11r)	Me	*b*	85	96	94:6	91	86	0	6
(11s)	Me	C_6H_{11}[c]	84	95	91:9	86	80	0	9
(11bb)[d]	Me	*e*	61	81	91:9	74	71	–	7
(11cc)	*f*	*f*	88[g]	75	*h*	75	98	0	—

[a] Combined yield of separated diastereoisomers. [b] 3,4-Methylenedioxyphenyl. [c] Cyclohexyl. [d] See ref. 31, product is feniculin (31). [e] 4-(3-Methylbut-2-enyloxy)phenyl. [f] Product is (30). [g] By oxidation of (11cc), see text. [h] Four diastereoisomers, not all separated.

Table 6.

Entry	R^1	R^2	Yield (%) (12)	Yield (%) (11)	*threo*: *erythro*	*threo* % isolated	Yield (%) *E*-alkene	Product	Ref.
1	Bu^n	$(CH_2)_4OH$	87	82	75:25	68	96	(20)	38
2	Et	$(CH_2)_5OH$	81	100	85:15	85	98	(21)	38
3	$(CH_2)_2OH$	Ph	96	92	95:5	92	82	(22)	38
4	*b*	Me	71	91	82:18	71	80	(23)	39
5	*b*	Bu^n	61	81	77:23	57	72	(23)	39
6	*b*	Ph	64	84	75:25	63	83	(23)	39
7	Me	$(CH_2)_4CO_2H$	79	82	75:25	62	93	(24)	40

[a] By intramolecular acyl transfer.[38] [b] $(CH_2)_2C(OCH_2CH_2O)Me$.

carried out using a 50 cm × 1 cm steel column packed with Lichrosorb SI 60 silica (10) and pressurised by an Altex 110A pump. Melting-points were determined on an Electrothermal apparatus and are uncorrected.

Microanalyses were carried out by technical staff at the University Chemical Laboratory, Cambridge using a Carlo Erba 1106 or Perkin-Elmer 240 automatic analyser.

Dry THF was freshly distilled from sodium wire using benzophenone radical as an indicator. Toluene and Et_2O were dried by distillation from sodium wire and were stored over sodium. Dichloromethane and DMSO were dried by distillation from CaH_2 and were stored over 4A molecular sieves. DMF was dried by distillation from 4A molecular sieves and was stored over 4A molecular sieves. All reactions in non-aqueous solutions were carried out under a nitrogen atmosphere.

Preparation of Alkyldiphenylphosphine Oxides

General Procedure from Phosphonium Salts.—Triphenylphosphine was heated under reflux with an excess of alkyl halide. The precipitated phosphonium salt was filtered off, washed well with ether, and then heated with 30% w/w aqueous sodium hydroxide (*ca.* 4 ml/g) until all the benzene had distilled out. The mixture was cooled and extracted with dichloromethane, and the extracts were dried ($MgSO_4$) and evaporated to dryness. In this way the following alkyldiphenylphosphine oxides were prepared.

Ethyldiphenylphosphine Oxide (6; R^1 = Me).—Triphenylphosphine (65.6 g, 0.25 mol) and iodoethane (42.9 g, 0.275 mol) in dry toluene (250 ml) gave the phosphonium salt (102.4 g, 97.9%) after 3.5 h. The phosphine oxide was obtained as needles (53.2 g, 92.5%), m.p. 123—124 °C (from EtOAc) (lit.,[44] 121 °C), δ($CDCl_3$) 7.9—7.3 (10 H, m, Ph_2PO), 2.3 (2 H, m, CH_2), and 1.2 (3 H, dt, J_{HMe} 7, J_{MeP} 17 Hz, Me).

Diphenylpropylphosphine Oxide (6; R^1 = Et).—Triphenylphosphine (26.2 g, 0.1 mol) and 1-bromopropane (98.4 g, 0.8 mol) gave the phosphonium salt (36.9 g, 96%) after 2 h. The phosphine oxide was obtained as needles (21.7 g, 88.9%), m.p. 99—100 °C (from EtOAc) (lit.,[45] 100—101 °C), δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 2.3 (2 H, m, PCH_2), 1.7 (2 H, m, CH_2Me), and 1.05 (3 H, t, *J* 7 Hz, Me).

Butyldiphenylphosphine Oxide (6; R^1 = Pr).—Triphenylphosphine (52.4 g, 0.2 mol) and 1-iodobutane (73.6 g, 0.4 mol) gave the phosphonium salt (83.6 g, 93.7%) after 20 min. The phosphine oxide was obtained as needles (44.4 g, 86.1%), m.p. 93—94 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (lit.,[45] 93—94 °C), δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 2.3 (2 H, m, PCH_2), 1.5 (4 H, m, CH_2CH_2Me), and 0.9 (3 H, t, *J* 7 Hz, Me).

Pentyldiphenylphosphine Oxide (6; R^1 = Bu).—Triphenylphosphine (26.2 g, 0.1 mol) and 1-bromopentane (60.4 g, 0.4 mol) gave the phosphonium salt (39.0 g, 94.4%) after 18 h. The *phosphine oxide* was obtained as needles (22.8 g, 83.8%), m.p. 78—79 °C [from EtOAc–light petroleum (b.p. 40—60 °C)] (Found: C, 75.1; H, 7.85; P, 11.16. $C_{17}H_{21}OP$ requires C, 74.9; H, 7.79; P, 11.39%), R_F 0.25; $\nu_{max.}$ 1 440 (P–Ph) and 1 183 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 2.3 (2 H, m, PCH_2), 1.8—1.2 (6 H, m, $CH_2CH_2CH_2Me$), and 0.85 (3 H, t, *J* 7 Hz, Me) (Found: M^+, 272.1331. $C_{17}H_{21}OP$ requires *M*,

272.1330), *m/z* 273 (4%, *M* + 1), 272 (30%), 215 (100%, $Ph_2POCH_2^+$), 202 (58%, Ph_2POH), and 201 (53%, Ph_2PO^+).

Isobutyldiphenylphosphine Oxide (**6**; R^1 = Pr^i).—Triphenylphosphine (26.2 g, 0.1 mol) and 1-bromo-2-methylpropane (54.8 g, 0.4 mol) gave the phosphonium salt (32.7 g, 82.0%) after 36 h. The phosphine oxide was obtained as needles (19.4 g, 75.2%), m.p. 135—136 °C (from EtOAc) (lit.,[46] 132.5—134 °C), δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 2.2 (3 H, m, CH_2CH), and 1.05 (6 H, d, *J* 7 Hz, 2 × Me).

(3-Methylbutyl)diphenylphosphine Oxide (**6**; R^1 = CH_2-$CHMe_2$).—Triphenylphosphine (26.2 g, 0.1 mol) and 1-bromo-3-methylbutane (60.4 g, 0.4 mol) gave the phosphonium salt (39.9 g, 96.6%) after 18 h. The phosphine oxide was obtained as needles (21.1 g, 77.6%), m.p. 98—99 °C [from EtOAc–light petroleum (b.p. 40—60 °C)] (lit.,[47] b.p. 96–97 °C), δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 2.3 (2 H, m, PCH_2), 1.6 (3 H, m, CH_2CH), and 0.9 (6 H, d, *J* 7 Hz, 2 × Me).

(Cyclohexylmethyl)diphenylphosphine Oxide (**6**; R^1 = cyclohexyl).—Triphenylphosphine (9.26 g, 35.3 mmol) and cyclohexylmethyl bromide (25.0 g, 141.2 mmol) gave the phosphonium salt (15.7 g, 100%) after 3 days. The *phosphine oxide* was obtained as microcrystals (8.4 g, 79.8%), m.p. 119—120 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 76.3; H, 7.95; P, 10.1. $C_{19}H_{23}OP$ requires C, 76.4; H, 7.78; P, 10.40%), R_F 0.4, $\nu_{max.}$ 1 180 cm^{-1} (P=O); δ($CDCl_3$) 7.85—7.4 (10 H, m, Ph_2PO), 2.2 (2 H, m, PCH_2), and 1.9—1.0 (11 H, m, C_6H_{11}) (Found: M^+, 298.1492. $C_{19}H_{23}OP$ requires *M*, 298.1487), *m/z* 299 (4%, *M* + 1), 298 (19%), 215 (100%, $Ph_2POCH_2^+$), and 201 (19%, Ph_2PO^+).

Benzyldiphenylphosphine Oxide (**6**; R^1 = Ph).—Chlorodiphenylphosphine (11.0 g, 49.8 mmol) in dry ether (30 ml) was added dropwise to benzyl alcohol (5.4 g, 49.8 mmol), dry pyridine (4.0 g, 50.6 mmol), and dry ether (90 ml) at −78 °C. The mixture was stirred at −78 °C for 1.5 h and then for 45 min at 25 °C before the pyridinium hydrochloride was filtered off under a blanket of nitrogen and the filtrate evaporated to dryness. The residual colourless oil was dissolved in dry toluene (150 ml) containing a small crystal of iodine or a drop of benzyl bromide and heated under reflux for 24 h. The mixture was cooled, filtered, and the product washed with a little dry toluene followed by plenty of dry ether to give the phosphine oxide (**6**; R^1 = Ph) as needles (10.2 g, 70.1%), m.p. 192—193 °C (from EtOAc—EtOH) (lit.,[48] 192—193 °C), R_F 0.35, δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 7.15 (5 H, br s, PhC) and 3.65 (2 H, d, *J* 14 Hz, CH_2). The reaction mother liquors were concentrated and cooled to give benzyl diphenylphosphinoate as needles (2.0 g, 13.1%), m.p. 77—78 °C (from ether) (lit.,[49] m.p. 78—78.5 °C), R_F 0.45, δ($CDCl_3$) 8.05—7.45 (10 H, m, Ph_2PO), 7.4 (5 H, s, PhC), and 5.1 (2 H, d, *J* 7 Hz, CH_2) (Found: M^+, 308.0955. Calc. for $C_{19}H_{17}O_2P$: *M*, 308.0966), *m/z* 309 (10%, *M* + 1), 308 (38%), 217 (6%, Ph_2PO_2), and 202 (100%, Ph_2POH).

[(4-Methoxyphenyl)methyl]diphenylphosphine Oxide (**6**; R^1 = 4-$MeOC_6H_4$).—The procedure used was the same as that for the phosphine oxide (**6**; R^1 = Ph). Chlorodiphenylphosphine (11.0 g, 49.8 mmol), 4-methoxybenzyl alcohol (6.88 g, 49.8 mmol), and dry pyridine (4.0 g, 50.6 mmol) gave the phosphine oxide (**6**; R^1 = 4-$MeOC_6H_4$) as needles (11.3 g, 70.2%), m.p. 227—228 °C (from MeOH) (lit.,[50] 230 °C), δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 7.1—6.6 (4 H, m, ArO), 3.7 (3 H, s, Me), and 3.6 (2 H, d, *J* 14 Hz, CH_2).

Preparation of β-Hydroxydiphenylphosphine Oxides (**11**) (*Table 3*)

General Procedure from Alkyldiphenylphosphine Oxides (**6**).—n-Butyl-lithium (1.5M-solution in hexane) was added from a syringe to a stirred solution of the phosphine oxide (**6**) in dry THF (*ca.* 30 ml/g) at 0 °C. After 30 min the red reaction solution was cooled to −78 °C (acetone–solid CO_2) and neat aldehyde was added dropwise at such a rate that the solution temperature was maintained at −78 °C. The pale yellow solution was allowed to warm to room temperature over *ca.* 2 h and then water was added. The THF was removed under reduced pressure and brine added to the aqueous residue before extraction with dichloromethane (3 ×). The combined organic extracts were dried ($MgSO_4$) and evaporated to dryness to give the product as a mixture of diastereoisomers. In this way the following β-hydroxydiphenylphosphine oxides were prepared.

2-Diphenylphosphinoyl-1-methylpropan-1-ol (**11a**).—Ethyldiphenylphosphine oxide (1.0 g, 4.35 mmol), n-butyl-lithium (1.5M in hexane; 2.9 ml), and acetaldehyde (267 mg, 4.79 mmol) gave a mixture of diastereoisomers of the alcohol (**11a**), separated by flash chromatography to give *erythro*-(**11a**) (822 mg, 69%), identified by n.m.r.; δ_H($CDCl_3$) 8.0—7.1 (10 H, m, Ph_2PO), 4.27 (1 H, ddq, J_{HMe} 7, J_{HP} 10, J_{HH} 2 Hz, MeC*H*OH), 4.1 (1 H, br s, OH), 2.34 (1 H, d quint, J_{HMe} = J_{HP} = 7, J_{HH} 2 Hz, PC*H*Me), 1.14 (3 H, d, J_{HMe} 7 Hz, *Me*CHOH), 1.15 (3 H, dd, J_{HMe} 7, J_{MeP} 17 Hz, PCH*Me*), and *threo*-(**11a**) (274 mg, 23%), identified by n.m.r. δ_H($CDCl_3$) 7.9—7.3 (10 H, m, Ph_2PO), 4.3 (1 H, br s, OH), 4.05 (1 H, dd quint, J_{HMe} = J_{HH} = 7, J_{HP} 12 Hz, MeC*H*OH), 2.71 (1 H, dd quint, J_{HMe} = J_{HH} = 7, J_{HP} 9 Hz, PC*H*Me), 1.22 (3 H, d, *J* 7 Hz, *Me*CHOH), and 1.03 (3 H, dd, J_{MeH} 7, J_{MeP} 18 Hz, PCH*Me*).

2-Diphenylphosphinoyl-1-phenylbutan-1-ol (**11c**; R^1 = Et, R^2 = Ph).—Diphenylpropylphosphine oxide (**6**; R^1 = Et) (1.0 g, 4.1 mmol), n-butyl-lithium (1.5M in hexane; 2.7 ml), and benzaldehyde (435 mg, 4.1 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography (elution with EtOAc then acetone). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11c**), needles (1.050 g, 73.4%), m.p. 157—159 °C (from EtOAc) (Found: C, 75.3; H, 6.69; P, 8.64. $C_{22}H_{23}O_2P$ requires C, 75.4; H, 6.62; P, 8.85%), R_F 0.5, $\nu_{max.}$ 3 270 (OH), 1 445 (P–Ph), and 1 160 cm^{-1} (P=O); δ($CDCl_3$) 8.15—7.4 (10 H, m, Ph_2PO), 7.4—7.2 (5 H, m, PhC), 5.3 (1 H, dd, J_{HH} 1, J_{HP} 9 Hz, C*H*OH), 4.7 (1 H, s, OH), 2.45 (1 H, ddt, J_{HH} 1, 5, 5, J_{HP} 7 Hz, CHP), 2.2—1.5 (2 H, m, CH_2), and 0.4 (3 H, t, J_{HH} 8 Hz, CH_2*Me*) (Found: M^+, 350.1455. $C_{22}H_{23}O_2P$ requires *M*, 350.1436), *m/z* 351 (2%, *M* + 1), 350 (1%), 244 (77%, Ph_2POPr), 229 (100%, $Ph_2POCH_2CH_2^+$), and 202 (45%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11b**), needles (180 mg, 12.6%), m.p. 165—167 °C (from EtOAc) (Found: C, 75.1; H, 6.72; P, 9.02. $C_{22}H_{23}O_2P$ requires C, 75.4; H, 6.62; P, 8.85%), R_F 0.4, $\nu_{max.}$ 3 140 (OH) and 1 050 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.1 (15 H, m, 3 × Ph), 5.5 (1 H, d, J_{HOH} 5 Hz, OH), 5.1 (1 H, dt, J_{HH} 7, J_{HP} 17 Hz, C*H*OH), 2.65 (1 H, ddt, J_{HH} = J_{HP} 7 Hz, CHP), 1.7—1.2 (2 H, m, CH_2), and 0.7 (3 H, t, J_{HH} 7 Hz, CH_2*Me*) (Found: M^+, 350.1395. $C_{22}H_{23}O_2P$ requires *M*, 350.1435), *m/z* 350 (1%), 244 (84%, Ph_2POPr), 229 (100%, $Ph_2POCH_2CH_2^+$), and 202 (26%, Ph_2POH).

2-Diphenylphosphinoyl-1-phenylpentan-1-ol (**11d**; R^1 = Pr, R^2 = Ph).—Butyldiphenylphosphine oxide (**6**; R^1 = Pr) (1.0 g, 3.87 mmol), n-butyl-lithium (1.5M in hexane; 2.6 ml), and benzaldehyde (0.41 g, 3.87 mmol) gave an oil which contained two diastereoisomers that were separated by flash column

chromatography (elution with EtOAc then acetone). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11d**), needles (1.123 g, 79.6%), m.p. 140—141 °C [from acetone–light petroleum (b.p. 60—80 °C)] (Found: C, 75.9; H, 6.88; P, 8.51. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.94; P, 8.52%), R_F 0.55, $\nu_{max.}$ 3 220 (OH), 1 440 [P(O)Ph], and 1 160 cm^{-1} (P=O); δ($CDCl_3$) 8.1—7.4 (10 H, m, Ph_2PO), 7.3 (5 H, m, PhC), 5.25 (1 H, dd, J_{HH} 1, J_{HP} 10 Hz, C*H*OH), 4.1 (1 H, s, OH), 2.45 (1 H, m, J_{HP} 7 Hz, CHP), 2.1—1.3 (2 H, m, $CHCH_2$), and 0.9—0.3 (5 H, m, CH_2Me) (Found: M^+, 364.1595. $C_{23}H_{25}O_2P$ requires *M*, 364.1592), *m*/*z* 364 (13%), 346 (58%, $M - H_2O$), 258 (45%, $Ph_2POCH_2CH_2Et$), 229 (100%, $Ph_2POCH_2CH_2^+$), and 201 (20%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11d**), needles (201 mg, 14.3%), m.p. 126—128 °C (from acetone–light petroleum b.p. 60—80 °C) (Found: C, 75.5; H, 7.03; P, 8.68. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.94; P, 8.52%), R_F 0.45, $\nu_{max.}$ 3 170 (OH), 1 440 (P–Ph), and 1 150 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.1 (15 H, m, 3 × Ph), 5.55 (1 H, d, J_{HOH} 5 Hz, OH), 5.05 (1 H, dt, J_{HOH} 5, J_{HH} 7, J_{HP} 17 Hz, C*H*OH), 2.75 (1 H, m, CHP), 1.65—0.8 (4 H, m, 2 × CH_2), and 0.65 (3 H, t, J_{HH} 7 Hz, CH_2*Me*) (Found: M^+, 364.1590. $C_{23}H_{25}O_2P$ requires *M*, 364.1592), *m*/*z* 364 (1%), 258 [50%, $Ph_2PO(CH_2)_3$-Me], and 202 (16%, Ph_2POH).

2-*Diphenylphosphinoyl*-1-*phenylhexan*-1-*ol* (**11e**; R^1 = Bu, R^2 = Ph).—Pentyldiphenylphosphine oxide (**6**; R^1 = Bu) (1.0 g, 3.67 mmol), n-butyl-lithium (1.5M in hexane; 2.5 ml), and benzaldehyde (0.39 g, 3.67 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)- adduct, *erythro*-(**11e**), needles (982 mg, 70.7%), m.p. 132—134 °C [from EtOAc–light petroleum (b.p. 60—80 °C] (Found: C, 75.8; H, 7.21; P, 8.11. $C_{24}H_{27}O_2P$ requires C, 76.1; H, 7.22; P, 8.19%), R_F 0.6, $\nu_{max.}$ 3 310 (OH), 1 440 (P–Ph) and 1 150 cm^{-1} (P=O); δ($CDCl_3$) 8.15—7.4 (10 H, m, Ph_2PO), 7.3 (5 H, m, PhC), 5.3 (1 H, dd, J_{HH} 1, J_{HP} 9 Hz, C*H*OH), 4.75 (1 H, s, OH), 2.45 (1 H, m, J_{HP} *ca.* 7 Hz, CHP), 2.0—1.4 (2 H, m, $CHCH_2$), 0.9—0.5 (4 H, m, 2 × CH_2), and 0.45 (3 H, t, J_{HH} 8 Hz, CH_2*Me*) (Found: M^+ 378.1737. $C_{24}H_{27}O_2P$ requires *M*, 378.1748); *m*/*z* 379 (13%, *M* + 1), 378 (5%), 272 (42%, $Ph_2POC_5H_{11}$), 229 (100%, $Ph_2POCH_2CH_2^+$), and 202 (40%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11e**), needles (191 mg, 13.7%), m.p. 120—121 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 76.1; H, 7.27; P, 8.28. $C_{24}H_{27}O_2P$ requires C, 76.1; H, 7.22; P, 8.19%), R_F 0.5, $\nu_{max.}$ 3 220 (OH), 1 440 (P–Ph), and 1 175 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.0 (15 H, m, 3 × Ph), 5.55 (1 H, d, J_{HOH} 5 Hz, OH), 5.0 (1 H, dt, J_{HOH} 5, J_{HH} 7, J_{HP} 17 Hz, C*H*OH), 2.7 (1 H, m, CHP), 1.65—1.2 (2 H, m, $CHCH_2$), 1.1—0.8 (4 H, m, 2 × CH_2), and 0.6 (3 H, t, J_{HH} 7 Hz, CH_2*Me*) (Found: M^+, 378.1712. $C_{24}H_{27}O_2P$ requires *M*, 378.1749), *m*/*z* 379 (3%, *M* + 1), 378 (2%), 272 (42%, $Ph_2POC_5H_{11}$), 229 (100%, $Ph_2POCH_2CH_2^+$), and 202 (53%, Ph_2POH).

2-*Diphenylphosphinoyl*-4-*methyl*-1-*phenylpentan*-1-*ol* (**11f**; R^1 = Bu^i, R^2 = Ph).—(3-Methylbutyl)diphenylphosphine oxide (**6**; R^1 = Bu^i) (1.0 g, 3.67 mmol), n-butyl-lithium, (1.5M in hexane; 2.5 ml), and benzaldehyde (0.39 g, 3.67 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11f**), needles (905 mg, 65.1%), m.p. 158—160 °C [from EtOAc–light petroleum (b.p. 60—80 °C] (Found: C, 75.9; H, 7.39; P, 8.50. $C_{24}H_{27}O_2P$ requires C, 76.1; H, 7.22; P, 8.19%), R_F 0.6, $\nu_{max.}$ 3 240 (OH), 1 440 (P–Ph), and 1 160 cm^{-1} (P=O); δ($CDCl_3$) 8.15—7.2 (15 H, m, 3 × Ph), 5.3 (1 H, dd, J_{HH} 1, J_{HP} 10 Hz, C*H*OH), 4.8 (1 H, br s, OH), 2.45 (1 H, dq, J_{HH} 1, 6, 6, J_{HP} 6 Hz, CHP), 2.0—1.2 (3 H, m, CH_2CH), 0.3 (3 H, d, J_{HMe} 5 Hz, Me*), and 0.2 (3 H, d, J_{HMe} 5 Hz, Me*) (Found: M^+, 378.1751. $C_{24}H_{27}O_2P$ requires *M*, 378.1749), *m*/*z* 379 (1%, *M* + 1), 378 (2%), 272 (30%, $Ph_2POCH_2CH_2CHMe_2$), 229 (100%, $Ph_2POCH_2CH_2^+$), and 202 (16%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11f**), needles (221 mg, 15.9%), m.p. 155—156 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 76.2; H, 7.20; P, 8.41. $C_{24}H_{27}O_2P$ requires C, 76.1; H, 7.22; P, 8.19%), R_F 0.5, $\nu_{max.}$ 3 260 (OH), 1 440 (P–Ph), and 1 160 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.0 (15 H, m, 3 × Ph), 5.7 (1 H, d, J_{HOH} 6 Hz, OH), 5.1 (1 H, ddd, J_{HH} = J_{HOH} = 6, J_{HP} 19 Hz, C*H*OH), 2.8 (1 H, m, J_{HP} 12 Hz, CHP), 1.9—1.0 (3 H, m, CH_2CH), and 0.65 (6 H, m, 2 × Me*) (Found: M^+, 378.1766. $C_{24}H_{27}O_2P$ requires *M*, 378.1748), *m*/*z* 379 (5%, *M* + 1), 378 (2%), 272 (30%, $Ph_2POCH_2CH_2CHMe$), 229 (100%, $Ph_2POCH_2CH_2^+$), and 201 (32%, Ph_2PO^+).

2-*Diphenylphosphinoyl*-3-*methyl*-1-*phenylbutan*-1-*ol* (**11g**; R^1 = Pr^i, R^2 = Ph).—Isobutyldiphenylphosphine oxide (**6**; R^1 = Pr^i) (1.0 g, 3.87 mmol), n-butyl-lithium (1.5M in hexane; 2.6 ml) and benzaldehyde (0.41 g, 3.87 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11g**), microcrystals (761 mg, 54.0%), m.p. 164—166 °C [from acetone–light petroleum (b.p. 60—80 °C)] (Found: C, 75.5; H, 7.04; P, 8.26. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.92; P, 8.51%), R_F 0.6, $\nu_{max.}$ 3 290 (OH), 1 440 (P–Ph), 1 180, and 1 165 cm^{-1}; δ($CDCl_3$) 8.1—7.4 (10 H, m, Ph_2PO), 7.2 (5 H, m, PhC), 5.35 (1 H, dd, J_{HH} 2, J_{HP} 9 Hz, C*H*OH), 4.6 (1 H, broad s, OH), 2.65 (1 H, ddd, J_{HH} = 2, 2, J_{HP} 9 Hz, CHP), 2.2 (1 H, m, $CHMe_2$), 1.05 (3 H, d, J_{HMe} 7 Hz, Me*), and 0.75 (3 H, d, J_{HMe} 7 Hz, Me*) (Found: M^+, 364.1619. $C_{23}H_{25}O_2P$ requires *M*, 364.1592), *m*/*z* 365 (10%, *M* + 1), 364 (20%), 258 (49%, $Ph_2POCH_2CHMe_2$), 243 [100%, $Ph_2PO(CH_2)_3^+$], and 201 (18%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11g**), needles (435 mg, 30.9%), m.p. 190—192 °C (from acetone) (Found: C, 75.5; H, 7.04; P, 8.43. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.92; P, 8.51%), R_F 0.5, $\nu_{max.}$ 3 290 (OH) and 1 145 cm^{-1} (P=O); δ($CDCl_3$) 7.85—6.9 (15 H, m, 3 × Ph), 5.8 (1 H, d, J_{HOH} 7 Hz, OH), 5.35 (1 H, ddd, J_{HH} 3, J_{HOH} 7, J_{HP} 22 Hz, C*H*OH), 2.7 (1 H, dt, J_{HH} = 3, 3, J_{HP} 10 Hz, CHP), 2.1 (1 H, m, $CHMe_2$), 1.25 (3 H, d, J_{HMe} 7 Hz, Me*), and 1.1 (3 H, d, J_{HMe} 7 Hz, Me*); *m*/*z* 258 (46%, $Ph_2POCH_2CHMe_2$), 243 ([100%, $Ph_2PO(CH_2)_3^+$], and 201 (46%, Ph_2PO^+).

1-*Cyclohexyl*-2-*diphenylphosphinoylpropan*-1-*ol* (**11s**; R^1 = Me, R^2 = cyclohexyl).—Ethyldiphenylphosphine oxide (**6**; R^1 = Me) (1.0 g, 4.35 mmol), n-butyl-lithium (1.5M in hexane; 2.9 ml), and cyclohexanecarbaldehyde (488 mg, 4.35 mmol) gave a crystalline material containing two diastereoisomers which were separated by flash column chromatography (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11s**), needles (1.020 g, 68.5%), m.p. 171—173 °C (from EtOAc) (Found: C, 73.6; H, 8.07; P, 9.10. $C_{21}H_{27}O_2P$ requires C, 73.6; H, 7.97; P, 9.06%), R_F 0.4; $\nu_{max.}$ 3 410 (OH), 1 440 (P–Ph), and 1 165 cm^{-1} (P=O); δ($CDCl_3$) 7.95—7.4 (10 H, m, Ph_2PO), 4.2 (1 H, br s, OH), 3.6 (1 H, dd, J_{HH} < 1, J_{HH} = J_{HP} = 10 Hz, C*H*OH), 2.6 (1 H, d quintet, J_{HH} < 1, J_{HMe} = J_{HP} = 7 Hz, CHP), 2.1 (1 H, br d, ring CH), and 1.9—0.7 (total 13 H, m overlain by dd at 1.15, J_{HMe} 7, J_{HP} 17 Hz, Me and ring CH_2's) (Found: M^+, 342.1740. $C_{21}H_{27}O_2P$ requires *M*, 342.1748), *m*/*z* 342 (4%), 259 (100%, *M* − cyclohexyl), 230 (37%, Ph_2POEt), and 201 (33%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the

column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11s**), needles (267 mg, 17.9%), m.p. 144—146 °C [from acetone–light petroleum (b.p. 60—80 °C)] (Found: C, 73.5; H, 7.86; P, 9.19. $C_{21}H_{27}O_2P$ requires C, 73.6; H, 7.97; P, 9.06%), R_F 0.35, $\nu_{max.}$ 3 290 (OH) and 1 150 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 4.8 (1 H, br s, OH), 3.7 (1 H, dd, J_{HH} < 1, J_{HH} 8, J_{HP} 12 Hz, C*H*OH), 2.8 (1 H, ddq, J_{HH} = J_{HMe} = 8, J_{HP} 11 Hz, CHP), and 1.85—0.9 (total 14 H, m overlain by dd at 1.0, J_{HMe} 8, J_{HP} 17 Hz, cyclohexyl and Me) (Found: M^+, 342.1759. $C_{21}H_{27}O_2P$ requires *M*, 342.1758), *m/z* 342 (1%), 259 (100%, *M* − cyclohexyl), 230 (29%, Ph_2POEt), and 201 (46%, Ph_2PO^+).

1-*Diphenylphosphinoyl*-1-*phenylpropan*-2-*ol* (**11u**; R^1 = Ph, R^2 = Me).—n-Butyl-lithium (1.5M in hexane; 2.3 ml) was added from a syringe to a stirred solution of benzyldiphenylphosphine oxide (**6**; R^1 = Ph) (1.0 g, 3.42 mmol) in dry THF (30 ml) at 0 °C. After 30 min the dark red reaction solution was cooled to −78 °C (acetone–solid CO_2) and acetaldehyde (166 mg, 3.76 mmol) added dropwise from a syringe at such a rate as to maintain the internal temperature at −78 °C. After 2 min the now pale yellow solution, *still at −78 °C*, was quenched by the addition of saturated aqueous ammonium chloride (30 ml). The mixture was allowed to warm to room temperature, the THF was removed under reduced pressure, and brine (15 ml) added to the aqueous residue before extraction with dichloromethane (3 × 30 ml). The organic phases were combined, dried ($MgSO_4$), and evaporated to dryness to give the product as an amorphous mixture of diastereoisomers. The isomers were separated by flash column chromatography (elution with EtOAc then acetone). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11u**) (810 mg, 70.4%), m.p. 163—165 °C (from EtOAc) (Found: C, 74.7; H, 6.42; P, 9.23. $C_{21}H_{21}O_2P$ requires C, 75.0; H, 6.31; P, 9.23%), R_F 0.45, $\nu_{max.}$ 3 390 (OH), 1 440 (P–Ph), and 1 160 cm^{-1} (P=O); δ[$(CD_3)_2SO$] 8.2—7.0 (15 H, m, 3 × Ph), 4.75 (1 H, d, J_{HOH} 3 Hz, OH), 4.3 (1 H, m, C*H*OH), 4.0 (1 H, dd, J_{HH} 3, J_{HP} 9 Hz, CHP), and 0.9 (3 H, d, J_{HMe} 7 Hz, Me); *m/z* 318 (33%, *M* − H_2O), 292 (100%, Ph_2POCH_2Ph), and 201 (44%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11u**) (309 mg, 26.9%), m.p. 203—205 °C (from acetone) (Found: C, 75.1; H, 6.05; P, 9.1. $C_{21}H_{21}O_2P$ requires C, 75.0; H, 6.31; P, 9.23%), R_F 0.35, $\nu_{max.}$ 3 350 (OH), 1 440 (P–Ph), and 1 165 cm^{-1} (P=O); δ[$(CD_3)_2SO$] 8.1—7.0 (15 H, m, 3 × Ph), 4.7 (1 H, br s, OH), 4.3 (1 H, m, C*H*OH), 4.05 (1 H, dd, J_{HH} = J_{HP} = 7 Hz, CHP), and 1.05 (3 H, d, J_{HMe} 7 Hz, Me); *m/z* 292 (100%, Ph_2POCH_2Ph) and 201 (70%, Ph_2PO^+).

1-*Diphenylphosphinoyl*-1-*phenylpentan*-2-*ol* (**11v**; R^1 = Ph, R^2 = Pr).—n-Butyl-lithium (1.5M in hexane; 2.3 ml) was added from a syringe to a stirred solution of benzyldiphenylphosphine oxide (**6**; R^1 = Ph) (1.0 g, 3.42 mmol) in dry THF (30 ml) at 0 °C. After 30 min the dark red reaction solution was cooled to −78 °C (acetone–solid CO_2) and butanal (247 mg, 3.42 mmol) was added dropwise from a syringe at such a rate as to maintain the internal temperature at −78 °C. The solution temperature was then allowed to reach *−50 °C* (over *ca.* 10 min), during which time the colour changed from red to pale yellow; saturated aqueous ammonium chloride (30 ml) was then added. The mixture was allowed to warm to room temperature, the THF was removed under reduced pressure and brine (15 ml) added to the aqueous residue before extraction with dichloromethane (3 × 30 ml). The organic phases were combined, dried ($MgSO_4$), and evaporated to dryness to give the product as a crystalline mixture of diastereoisomers. The isomers were separated by flash column chromatography (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11v**) (779 mg, 62.3%), m.p. 198—199 °C [from EtOAc–light petroleum (b.p. 40—60 °C)] (Found: C, 75.8; H, 7.01; P, 8.57. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.93; P, 8.51%), R_F 0.6, $\nu_{max.}$ 3 360 (OH), 1 440 (P–Ph), and 1 150 cm^{-1} (P=O); δ[$(CD_3)_2SO$] 8.3—7.4 (10 H, m, Ph_2PO), 7.4—7.0 (5 H, m, PhC), 4.8 (1 H, d, *J* 2 Hz, C*H*OH), 4.2—3.9 (2 H, m, CHP and OH), 1.4—1.05 (4 H, m, 2 × CH_2), and 0.7 (3 H, t, J_{HMe} 5 Hz, Me); *m/z* 363 (3%, *M* − 1), 292 (100%, Ph_2POCH_2Ph), and 201 (18%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11v**) (383 mg, 30.6%), m.p. 208—210 °C [from EtOAc–light petroleum (b.p. 40—60 °C)] (Found: C, 75.6; H, 6.98; P, 8.43. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.93; P, 8.51%), R_F 0.45, $\nu_{max.}$ 3 320 (OH), 1 440 (P–Ph), and 1 165 cm^{-1} (P=O); δ[$(CD_3)_2SO$] 8.2—7.05 (15 H, m, 3 × Ph), 4.8 (1 H, d, *J* 5 Hz, C*H*OH), 4.1 (2 H, m, CHP and OH), 1.6—1.0 (4 H, m, 2 × CH_2), and 0.7 (3 H, m, Me); *m/z* 292 (100%, Ph_2POCH_2Ph) and 201 (25%, Ph_2PO^+).

1-*Diphenylphosphinoyl*-4-*methyl*-1-*phenylpentan*-2-*ol* (**11w**; R^1 = Ph, R^2 = Bu^i).—n-Butyl-lithium (1.5M in hexane; 2.3 ml) was added from a syringe to a stirred solution of benzyldiphenylphosphine oxide (**6**; R^1 = Ph) (1.0 g, 3.42 mmol) in dry THF (30 ml) at 0 °C. After 30 min the dark red reaction solution was cooled to −78 °C (acetone–solid CO_2) and 3-methylbutanal (295 mg, 3.42 mmol) added dropwise from a syringe at such a rate as to maintain the internal temperature at −78 °C. The solution temperature was then allowed to reach *−50 °C* (over *ca.* 10 min), during which time the colour lightened to orange, before saturated aqueous ammonium chloride (30 ml) was added. The mixture was allowed to warm to room temperature before removal of the THF under reduced pressure and dilution of the aqueous residue with brine (15 ml). The product was extracted with dichloromethane (3 × 30 ml), the organic phases combined, dried ($MgSO_4$), and evaporated to dryness to give a crystalline mixture of diastereoisomers. The isomers were separated by h.p.l.c. (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct, *erythro*-(**11w**) (614 mg, 47.6%), m.p. 183—185 °C [from EtOAc–light petroleum (b.p. 40—60 °C)] (Found: C, 76.3; H, 7.20; P, 8.00. $C_{24}H_{27}O_2P$ requires C, 76.1; H, 7.21; P, 8.20%), R_F 0.6, $\nu_{max.}$ 3 370 (OH), 1 440 (P–Ph), and 1 150 cm^{-1} (P=O); δ($CDCl_3$) 8.1—7.0 (15 H, m, 3 × Ph), 4.5—4.2 (2 H, m, CHOH), 3.35 (1 H, dd, *J* 2 and 9 Hz, CHP), 1.8—1.4 (1 H, m, C*H*Me_2), 1.3—0.95 (2 H, m, CH_2), and 0.7 (6 H, m, 2 × Me*); *m/z* 292 (100%, Ph_2POCH_2Ph) and 201 (32%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct, *threo*-(**11w**) (252 mg, 19.5%), m.p. 208—210 °C [from EtOAc–light petroleum (b.p. 40—60 °C)] (Found: C, 76.1; H, 7.21; P, 8.08. $C_{24}H_{27}O_2P$ requires C, 76.1; H, 7.21; P, 8.20%), R_F 0.6, $\nu_{max.}$ 3 370 (OH), 1 440 (P–Ph), and 1 165 cm^{-1} (P=O); δ($CDCl_3$) 8.0—6.85 (15 H, m, 3 × Ph), 4.5 (1 H, m, C*H*OH), 4.15 (1 H, br s, OH), 3.65 (1 H, dd, J_{HH} = J_{HP} = 8 Hz, CHP), 2.1—1.55 (1 H, m, C*H*Me_2), 1.5—0.95 (2 H, m, CH_2), and 0.7 (6 H, m, 2 × Me*); *m/z* 292 (100%, Ph_2POCH_2Ph) and 201 (33%, Ph_2PO^+).

Temperature Effects (*Table 2*)

2-*Diphenylphosphinoyl*-1-*phenylbutan*-1-*ol* (**11c**; R^1 = Et, R^2 = Ph).—*Experiment 1.* n-Butyl-lithium (1.5M in hexane; 0.68 ml) was added from a syringe to a stirred solution of diphenylpropylphosphine oxide (**6**; R^1 = Et) (250 mg, 1.02 mmol) in dry THF (15 ml) at 0 °C. After 30 min the orange reaction solution was cooled to *10 °C* (ice–water) and benzaldehyde (109 mg, 1.02 mmol) added dropwise from a syringe at such a rate as to maintain the internal temperature at 10 °C. The pale yellow reaction solution was allowed to warm to room temperature (over *ca.* 30 min) and water (10 ml) was

added before removal of the THF under reduced pressure. The aqueous residue was diluted with brine (10 ml) extracted with dichloromethane (3 × 20 ml), and the combined organic extracts dried ($MgSO_4$) and evaporated to dryness to give a crystalline mixture of diastereoisomers (350 mg, 97.5%). The isomers were not separated, but n.m.r. analysis of the corresponding methyl signals indicated that the product consisted of a 66:34 mixture of the (1*RS*, 2*SR*)- and (1*RS*, 2*RS*)-adducts respectively, *erythro*- and *threo*-(**11c**).

Experiment 2. The procedure was the same as that for experiment 1, except that benzaldehyde was added to the reaction solution at *−78 °C*. Thus, diphenylpropylphosphine oxide (**6**; R^1 = Et) (250 mg, 1.02 mmol), n-butyl-lithium (1.5M in hexane; 0.68 ml), and benzaldehyde (109 mg, 1.02 mmol) gave a crystalline mixture of diastereoisomers (350 mg, 97.5%) which, by n.m.r. analysis, was judged to consist of an 85:15 mixture of the (1*RS*, 2*SR*)- and (1*RS*, 2*RS*)-adducts respectively. The yield and adduct ratio did not change when the reaction was quenched with water either at −78 °C after 5 min or at 25 °C, 2 h or 96 h after the addition of benzaldehyde.

Experiment 3. The procedure used was the same as that for experiment 1, except that benzaldehyde was added to the reaction solution at *−100 °C* (methanol–liquid nitrogen). Thus, diphenylpropylphosphine oxide (**6**; R^1 = Et) (250 mg, 1.02 mmol), n-butyl-lithium (1.5M in hexane; 0.68 ml), and benzaldehyde (109 mg, 1.02 mmol) gave a crystalline mixture of diastereoisomers (350 mg, 97.5%) which, by n.m.r. analysis, consisted of a 92:8 mixture of the (1*RS*, 2*SR*)- and (1*RS*, 2*RS*)-adducts respectively.

3-*Methyl*-1-*phenyl*-2-*diphenylphosphinoylbutan*-1-*ol* (**11g**; R^1 = Pr^i, R^2 = Ph).—*Experiment 1.* The procedure used was the same as that described for phosphine oxide (**11c**) except that benzaldehyde was added to the reaction solution at *−100 °C* (methanol–liquid nitrogen). Thus, (s-butyldiphenylphosphine oxide (**6**; R^1 = Pr^i) (258 mg, 1.0 mmol), n-butyl-lithium 1.5M in hexane; 0.67 ml), and benzaldehyde (106 mg, 1.0 mmol) gave a crystalline mixture of diastereoisomers (360 mg, 98.9%) which, by n.m.r. analysis of the corresponding methyl signals, was judged to consist of an 83:17 mixture of the (1*RS*, 2*SR*)- and (1*RS*, 2*RS*)-adducts respectively, *erythro*- and *threo*-(**11g**).

Solvent Effects (*Table 1*)

1-*Phenyl*-2-*diphenylphosphinoylbutan*-1-*ol* (**11c**; R^1 = Et, R^2 = Ph).—n-Butyl-lithium (1.5M in hexane; 0.68 ml) was added from a syringe to a stirred solution of diphenylpropylphosphine oxide (**6**; R^1 = Et) (250 mg, 1.02 mmol) in dry solvent (15 ml) at 0 °C. After 30 min the orange reaction solution was cooled to —78 °C (acetone–solid CO_2) and benzaldehyde (109 mg, 1.02 mmol) added dropwise from a syringe at such a rate as to maintain the internal temperature at −78 °C. The work-up was carried out as described above. Table 1, lists the diastereoisomeric ratios obtained with the following solvents: (1) pentane, (2) toluene, (3) Et_2O, (4) DME, (5) THF, (6) THF with TMEDA (119 mg, 1.02 mmol), and (7) THF with DMI (234 mg, 2.05 mmol).

Completion of the Horner-Wittig Reaction (*Table 3*)

The procedure described below is typical of the method used for the decomposition of phosphine oxide adducts (**11**) listed in Table 3. Similar reactions have not all been individually described because the work-up procedure given below was generally used throughout.

Attempted Preparation of (Z)-1-*Phenylprop*-1-*ene* (**4**; R^1 = Me, R^2 = Ph) *from* erythro-(**11u**).—Sodium hydride (80% dispersion in oil; 60 mg, 2.0 mmol) was added in one portion to a stirred solution of the (1*RS*, 2*SR*)-adduct (**11u**) (336 mg, 1.0 mmol) in dry DMF (25 ml). The clear reaction solution was warmed to 50 °C for *ca.* 1 h by which time a white solid had precipitated. The reaction mixture was cooled and the precipitate dissolved by the addition of water (20 ml). The mixture was diluted with brine (20 ml) and extracted with Et_2O (3 × 30 ml). The organic phases were combined, washed with water (3 × 40 ml), dried ($MgSO_4$), and the solvent removed under reduced pressure. Bulb-to-bulb distillation (Kugelrohr apparatus) gave an isomeric mixture of alkenes *E*- and *Z*-(**4u**) (92 mg, 78.0%) as judged by n.m.r. and i.r. analysis. G.l.c. (column 1 and 2) showed the product to consist of a 50:50 mixture of the *E*- and *Z*-alkenes. The distillation residue (50 mg) was benzyldiphenylphosphine oxide.

(E)-1-*Phenylprop*-1-*ene E*-(**4u**; R^1 = Ph, R^2 = Me).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11u**) (200 mg, 0.6 mmol) and sodium hydride (50% dispersion in oil; 58 mg, 1.2 mmol) gave after distillation, the alkene (**11u**) (60 mg, 85.7%) as a colourless liquid. The *Z*-isomer was not detected by g.l.c. (columns 1 and 2).

(Z)-1-*Phenylbut*-1-*ene Z*-(**4c**; R^1 = Et, R^2 = Ph).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11c**) (800 mg, 2.28 mmol) and sodium hydride (80% dispersion in oil; 136 mg, 4.56 mmol) gave after distillation, the alkene *Z*-(**4c**) (238 mg, 78.8%) as a colourless liquid, b.p. 79—81 °C/20 mmHg (lit.,[51] b.p. 80—83 °C at 20 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 1 445, 915, 800, 764, and 696 cm^{-1} (C–H out of plane def.); δ(CCl_4) 7.2 (5 H, br s, Ph), 6.35 (1 H, dt, J_{HH} 2, J_{cis} 11 Hz, PhC*H*), 5.6 (1 H, dt, J_{HH} 7, J_{cis} 11 Hz, C*H*CH_2), 2.35 (2 H, d, quint, J_{HCH} 2, J_{HCH} = J_{HMe} = 7 Hz, CH_2), and 1.1 (3 H, t, J_{HMe} 7 Hz, Me). The *E*-isomer was not detected by g.l.c. (column 2).

(E)-1-*Phenylbut*-1-*ene E*-(**4c**; R^1 = Et, R^2 = Ph).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11c**) (800 mg, 2.28 mmol) and sodium hydride (80% dispersion in oil; 136 mg, 4.56 mmol) gave after distillation, the alkene *E*-(**4c**) (269 mg, 89.1%) as a colourless liquid, b.p. 89—91 °C at 20 mmHg (lit.,[51] b.p. 89—91 °C at 20 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 963 (C–H out of plane def.), 741, and 694 cm^{-1}; δ(CCl_4) 7.2 (5 H, m, Ph), 6.35 (1 H, d, J_{HH} 16 Hz, PhC*H*), 6.15 (1 H, dt, J_{HH} 6, 6, 16 Hz, C*H*CH_2), 2.25 (2H, dq, J_{HH} 6, J_{HMe} 7 Hz, CH_2), and 1.15 (3 H, t, J_{HMe} 7 Hz, Me). The *Z*-isomer was not detected by g.l.c. (column 2).

(Z)-1-*Phenylpent*-1-*ene Z*-(**4d**; R^1 = Pr, R^2 = Ph).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11d**) (600 mg, 1.65 mmol) and sodium hydride (80% dispersion in oil; 99 mg, 3.3 mmol) gave after distillation, the alkene *Z*-(**4d**) (193 mg, 80.1%) as a colourless liquid, b.p. 87—89 °C at 20 mmHg (lit.,[52] b.p. 79—80.6 °C at 11.5 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 1 445, 912, 768, and 698 cm^{-1} (C–H out of plane def.); δ(CCl_4) 7.2 (5 H, br s, Ph), 6.35 (1 H, dt, J_{HH} 2, 2, 11 Hz, PhC*H*), 5.55 (1 H, dt, J_{HH} 7, 7, 11 Hz, C*H*CH_2), 2.25 (2 H, tq, J_{HH} = 2, 2, 7, 7, 7 Hz, $CHCH_2$), 1.5 (2 H, sextuplet, J_{HH} 7 Hz, CH_2CH_2Me), and 0.95 (3 H, t, J_{HMe} 7 Hz, Me).[53] G.l.c. analysis (column 2) showed that the product contained *ca.* 2% of the *E*-isomer.

Attempted Preparation of (Z)-1-*Phenylpent*-1-*ene, Z*-(**4d**; R^1 = Ph, R^2 = Pr).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11v**) (270 mg, 0.74 mmol) and sodium hydride (80% dispersion in oil; 22 mg, 0.74 mmol) gave after distillation, an isomeric mixture of alkenes *E*- and *Z*-(**4d**) (78 mg, 72.2%) as judged by n.m.r. and i.r. G.l.c. (column 2) showed the product was a 33:67 mixture of the *Z*- and *E*-isomers respectively. The distillation residue (54 mg) was benzyldiphenylphosphine oxide.

(E)-1-*Phenylpent*-1-*ene* *E*-(**4d**; R^1 = Pr, R^2 = Ph).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11d**) (700 mg, 1.92 mmol) and sodium hydride (80% dispersion in oil; 115 mg, 3.84 mmol) gave after distillation, the alkene *E*-(**4d**) (259 mg, 92.2%) as a colourless liquid, b.p. 100—101 °C at 20 mmHg (lit.,[52] b.p. 86—86.5 °C at 10 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 964 (C–H out of plane def.), 747, 738, and 694 cm^{-1}; $\delta(CCl_4)$ 7.2 (5 H, m, Ph), 6.35 (1 H, d, J_{HH} 16 Hz, PhC*H*), 6.1 (1 H, dt, J_{HH} 6, 6, 16 Hz, C*H*CH_2), 2.2 (2 H, dt, J_{HH} 6, 7, 7, Hz, CHC*H*$_2$), 1.5 (2 H, sextuplet, *J* 7 Hz, CH_2CH_2Me), and 1.0 (3 H, t, J_{HMe} 7 Hz, Me).[54] The *Z*-isomer was not detected by g.l.c. (column 2).

(E)-1-*Phenylpent*-1-*ene* *E*-(**4d**; R^1 = Ph, R^2 = Pr).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11v**) (240 mg, 0.66 mmol) and sodium hydride (80% dispersion in oil; 20 mg, 0.66 mmol) gave after distillation, the alkene *E*-(**4d**) (90 mg, 93.8%) as a colourless liquid with i.r. and n.m.r. spectra identical with those obtained above. The *Z*-isomer was not detected by g.l.c. (column 2).

(Z)-1-*Phenylhex*-1-*ene* *Z*-(**4e**; R^1 = Bu, R^2 = Ph).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11e**) (810 mg, 2.14 mmol) and sodium hydride (80% dispersion in oil; 129 mg, 4.28 mmol) gave after distillation, the alkene *Z*-(**4e**) (288 mg, 85.2%) as a colourless liquid, b.p. 91—94 °C at 20 mmHg (lit.,[52] b.p. 76—76.5 °C at 7 mmHg), R_F 0.74, $\nu_{max.}$ (liquid film) 769 and 699 cm^{-1} (C–H out of plane def.); $\delta(CCl_4)$ 7.2 (5 H, br s, Ph), 6.35 (1 H, dt, J_{HH} 2, 2, 12 Hz, PhC*H*), 5.6 (1 H, dt, J_{HH} 7, 7, 12 Hz, C*H*CH_2), 2.3 (2 H, m, CHCH_2), 1.4 (4 H, m, CH_2CH_2Me), and 0.9 (3 H, m, Me). G.l.c. analysis (column 2) showed that the product contained *ca.* 4% of the *E*-isomer.

(E)-1-*Phenylhex*-1-*ene* *E*-(**4e**; R^1 = Bu, R^2 = Ph).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11e**) (700 mg, 1.85 mmol) and sodium hydride (80% dispersion in oil; 111 mg; 3.7 mmol) gave after distillation, the alkene *E*-(**4e**) (270 mg, 91.2%) as a colourless liquid, b.p. 100—103 °C at 20 mmHg (lit.,[52] b.p. 84 °C at 6.5 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 964 (C–H out of plane def.), 747, and 692 cm^{-1}; $\delta(CCl_4)$ 7.2 (5 H, m, Ph), 6.3 (1 H, d, J_{HH} 16 Hz, PhC*H*), 6.1 (1 H, dt, J_{HH} 6, 6, 16 Hz, C*H*CH_2), 2.2 (2 H, dt, J_{HH} 6, 7, 7 Hz, CHCH_2), 1.4 (4 H, m, CH_2CH_2Me), and 0.95 (3 H, m, Me). The *Z*-isomer was not detected by g.l.c. (column 2).

(Z)-4-*Methyl*-1-*phenylpent*-1-*ene* *Z*-(**4f**; R^1 = Bu^i, R^2 = Ph).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11f**) (625 mg, 1.65 mmol) and sodium hydride (80% dispersion in oil; 99 mg, 3.3 mmol) gave after distillation, the alkene *Z*-(**4f**) (227 mg, 86%) as a colourless liquid, b.p. 104—107 °C at 20 mmHg (lit.,[55] b.p. 107 °C at 11 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 770 and 700 cm^{-1} (C–H out of plane def.); $\delta(CCl_4)$ 7.15 (5 H, br s, Ph), 6.4 (1 H, dt, J_{HH} 2, 2, 11 Hz PhC*H*), 5.6 (1 H, dt, J_{HH} 7, 7, 11 Hz, C*H*CH_2), 2.2 (2 H, dt, J_{HH} 7, 7, 2 Hz, =CHCH_2), 1.7 (1H, nonet, J_{HH} 7 Hz, C*H*Me_2), and 0.95 (6 H, d, *J* 7 Hz, 2 × Me). G.l.c. analysis (column 2) showed that the product contained *ca.* 3% of the *E*-isomer.

Attempted Preparation of (Z)-4-*Methyl*-1-*phenylpent*-1-*ene* *Z*-(**4f**).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11w**) (350 mg, 0.93 mmol) and sodium hydride (80% dispersion in oil; 56 mg, 1.85 mmol) gave after distillation, an isomeric mixture of alkenes *E*- and *Z*-(**4f**) (120 mg, 81.1%) by n.m.r. and i.r. G.l.c. (column 2) showed the product was a 13:87 mixture of the *Z*- and *E*-isomers respectively. The distillation residue (49 mg) was benzyldiphenylphosphine oxide and 3-methylbutanal.

(E)-4-*Methyl*-1-*phenylpent*-1-*ene* *E*-(**4f**; R^1 = Bu^i, R^2 = Ph).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11w**) (700 mg, 1.85 mmol) and sodium hydride (80% dispersion in oil; 111 mg, 3.7 mmol) gave after distillation, the alkene *E*-(**4f**) (282 mg, 95.3%) as a colourless liquid, b.p. 115—118 °C at 20 mmHg (lit., [55] 107 °C at 11 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 964 (C–H out of plane def.), 741, and 693 cm^{-1}; $\delta(CCl_4)$ 7.15 (5 H, m, Ph), 6.3 (1 H, d, J_{HH} 16 Hz, PhC*H*), 6.05 (1 H, dt, J_{HH} 6, 6, 16 Hz, C*H*CH_2), 2.05 (2 H, dd, J_{HH} 6, 7 Hz, =CHCH_2), 1.7 (1 H, nonet, *J* 7 Hz, C*H*Me_2), and 0.95 (6 H, d, J_{HMe} 7 Hz, 2 × Me). G.l.c. analysis (column 2) showed that the product contained *ca.* 1% of the *Z*-isomer.

(E)-4-*Methyl*-1-*phenylpent*-1-*ene* *E*-(**4f**).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11w**) (140 mg, 0.37 mmol) and sodium hydride (80% dispersion in oil; 22 mg, 0.74 mmol) gave after distillation, the alkene *E*-(**4f**) (50 mg, 84.7%) as a colourless liquid with i.r. and n.m.r. spectra identical with those obtained above. The *Z*-isomer was not detected by g.l.c. (column 2).

(Z)-3-*Methyl*-1-*phenylbut*-1-*ene* *Z*-(**4g**; R^1 = Pr^i, R^2 = Ph).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11g**) (500 mg, 1.37 mmol) and sodium hydride (80% dispersion in oil; 82 mg, 2.74 mmol) gave after distillation, the alkene *Z*-(**4g**), (157 mg, 78.1%) as a colourless liquid, b.p. 80—82 °C at 20 mmHg (lit.,[52] b.p. 73—74 °C at 13.5 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 927, 792, 764, and 700 cm^{-1} (C–H out of plane def.); $\delta(CCl_4)$ 7.15 (5 H, br s, Ph), 6.25 (1 H, d, J_{HH} 11 Hz, PhC*H*), 5.4 (1 H, dd, J_{HH} 10, 11 Hz, =C*H*CH), 2.9 (1 H, d septuplet, J_{HMe} 7, J_{HH} 10 Hz, C*H*Me_2), and 1.05 (6 H, d, J_{HMe} 7 Hz, 2 × Me).[51] The *E*-isomer was not detected by g.l.c. (column 2).

(E)-3-*Methyl*-1-*phenylbut*-1-*ene* *E*-(**4g**; R^1 = Pr^i, R^2 = Ph).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11g**) (500 mg, 1.37 mmol) and sodium hydride (50% dispersion in oil; 132 mg, 2.75 mmol) gave after distillation, the alkene *E*-(**4g**) (170 mg, 84.6%) as a colourless liquid, b.p. 91—93 °C at 20 mmHg (lit.,[52] b.p. 85 °C at 12.5 mmHg), R_F 0.75, $\nu_{max.}$ (liquid film) 969 (C–H out of plane def.), 748, and 691 cm^{-1}; $\delta(CCl_4)$ 7.2 (5 H, m, Ph), 6.3 (1 H, d, *J* 16 Hz, PhC*H*), 6.05 (1 H, dd, J_{HH} 6, 16 Hz, =C*H*CH), 2.45 (1 H, d septuplet, J_{HH} 6, J_{HMe} 7 Hz, C*H*Me_2), and 1.1 (6 H, d, J_{HMe} 7 Hz, 2 × Me).[51] The *Z*-isomer was not detected by g.l.c. (column 2).

(Z)-1-*Cyclohexylprop*-1-*ene* *Z*-(**4s**; R^1 = Me, R^2 = cyclohexyl).—In the same way, the (1*RS*, 2*SR*)-adduct, *erythro*-(**11s**) (250 mg, 0.73 mmol) and sodium hydride (80% dispersion in oil; 24 mg, 0.80 mmol) gave after distillation, the alkene *Z*-(**4s**) (72 mg, 79.1%) as a colourless liquid, b.p. 51—55 °C at 20 mmHg (lit.,[56] 150 °C at 750 mmHg), $\nu_{max.}$ (liquid film) 1 450, 710 (C–H out of plane def.), and 600 cm^{-1}; $\delta(CDCl_3)$ 5.55—5.1 (2 H, m, CH=CH), 2.35 (1 H, br d, ring CH), and 1.9—0.9 (13 H, m, Me and ring CH_2s). The *E*-isomer was not detected by g.l.c. (column 3).

(E)-1-*Cyclohexylprop*-1-*ene* *E*-(**4s**; R^1 = Me, R^2 = cyclohexyl).—In the same way, the (1*RS*, 2*RS*)-adduct, *threo*-(**11s**) (250 mg, 0.73 mmol) and sodium hydride (80% dispersion in oil; 22 mg, 0.73 mmol) gave after distillation, the alkene *E*-(**4s**) (73 mg, 80.2%) as a colourless liquid, b.p. 61—63 °C at 20 mmHg (lit.,[57] b.p. 143—144 °C at 760 mmHg), $\nu_{max.}$ (liquid film) 1 450, 970 (C–H out of plane def.), and 600 cm^{-1}; $\delta(CCl_4)$ 5.25 (2 H, m, CH=CH) and 1.9—0.8 (14 H, m, Me and cyclohexyl). The *Z*-isomer was not detected by g.l.c. (column 3). The distillation residue (55 mg) was unchanged adduct (**11s**).

Preparation of α-Diphenylphosphinoyl Ketones (*Table 5*)

2-*Diphenylphosphinoyl*-1-*phenylbutan*-2-*one*.—*n-Butyllithium* (1.5M in hexane; 14.7 ml) was added dropwise from a

syringe to a stirred solution of diphenylpropylphosphine oxide (**6**; R^1 = Et) (4.88 g, 0.02 mol), in dry THF (70 ml) at 0 °C. After 30 min the red reaction solution was cooled to −78 °C (acetone–solid CO_2) and ethyl benzoate (3.0 g, 0.02 mol) was added dropwise from a syringe. The pale yellow solution was allowed to reach room temperature, saturated aqueous ammonium chloride was added, and the THF removed under reduced pressure. The aqueous residues were diluted with brine (20 ml) and extracted with dichloromethane (3 × 30 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated to give the ketone (**12c**; R^1 = Et, R^2 = Ph) as needles (4.5 g, 64.7%), m.p. 157—159 °C (from EtOAc) (lit.,[19] m.p. 156—159 °C), R_F 0.3, $\nu_{max.}$ 1 675 (C=O), 1 440 (P–Ph), 1 200, and 1 170 cm^{-1}; δ($CDCl_3$) 8.1—7.2 (15 H, m, 3 × Ph), 4.5 (1 H, ddd, J_{HH} 4, 11, J_{HP} 16 Hz, CHP), 2.5—1.9 (2 H, m, CH_2), and 1.0 (3 H, t, J_{HH} 7 Hz, Me).

2-*Diphenylphosphinoyl*-1-*phenylpentan*-1-*one* (**12d**; R^1 = Pr, R^2 = Ph).—In the same way, butyldiphenylphosphine oxide (**6**; R^1 = Pr) (5.16 g, 0.02 mol), n-butyl-lithium (1.5M in hexane; 13.3 ml) and ethyl benzoate (1.5 g, 0.01 mol) gave the *ketone* (**12d**) (3.0 g, 83.3% based on ethyl benzoate) after flash column chromatography (elution with EtOAc), m.p. 154—155 °C (from EtOAc) (Found: C, 76.5; H, 6.46; P, 8.60. $C_{23}H_{23}O_2P$ requires C, 76.2; H, 6.41; P, 8.56%), R_F 0.5, $\nu_{max.}$ 1 670 (C=O), 1 445 (P–Ph), and 1 190 cm^{-1} (P=O); δ($CDCl_3$) 8.05—7.2 (15 H, m, 3 × Ph), 4.55 (1 H, ddd, J_{HH} 4, 11, J_{HP} 16 Hz, CHP), 2.5—1.75 (2 H, m, $CHCH_2$), 1.35 (2 H, quintet, J_{HH} 7 Hz, CH_2Me), and 0.85 (3 H, t, J 7 Hz, Me) (Found: M^+, 362.1442. $C_{23}H_{23}O_2P$ requires M, 362.1436), m/z 363 (6%, M + 1), 362 (15%), 320 (98%, M − Pr), 219 (82%), and 201 (100%, Ph_2PO^+).

2-*Diphenylphosphinoyl*-1-*phenylhexan*-1-*one* (**12e**; R^1 = Bu, R^2 = Ph.—In the same way, pentyldiphenylphosphine oxide (**6**; R^1 = Bu) (8.2 g, 0.03 mol), n-butyl-lithium (1.5M in hexane; 20 ml) and ethyl benzoate (2.25 g, 0.015 mol) gave the *ketone* (**12e**), (4.6 g, 80.7% based on ethyl benzoate) after flash column chromatography (elution with EtOAc) as needles, m.p. 145—146 °C (from EtOAc) (Found: C, 76.6; H, 6.65; P, 8.45. $C_{24}H_{25}O_2P$ requires C, 76.6; H, 6.71; P, 8.24%), R_F 0.4, $\nu_{max.}$ 1 670 (C=O), 1 440 (P–Ph), and 1 190 cm^{-1} (P=O); δ($CDCl_3$) 8.1—7.2 (15 H, m, 3 × Ph), 4.6 (1 H, ddd, J_{HH} 4, 11, J_{HP} 16 Hz, CHP), 2.5—1.8 (2 H, m, $CHCH_2$), 1.3 (4 H, m, CH_2CH_2Me), and 0.8 (3 H, distorted t, J 6 Hz, Me) (Found: M^+, 376.1598. $C_{24}H_{25}O_2P$ requires M, 376.1592), m/z 377 (3%, M + 1), 376 (18%), 320 (100%, M − Bu), 219 (70%), 202 (85%, Ph_2POH), and 201 (85%, Ph_2PO^+).

2-*Diphenylphosphinoyl*-3-*methyl*-1-*phenylbutan*-1-*one* (**12g**; R^1 = Pr^i, R^2 = Ph).—In the same way, isobutyldiphenylphosphine oxide (**6**; R^1 = Pr^i) (5.16 g, 0.02 mol), n-butyl-lithium (1.5M in hexane; 13.3 ml), and ethyl benzoate (1.5 g, 0.01 mol) gave the *ketone* (**12g**) (2.5 g, 69.4% based on ethyl benzoate) after flash column chromatography (elution with EtOAc), m.p. 173—175 °C (from EtOAc) (Found: C, 76.0; H, 6.22; P, 8.49. $C_{23}H_{23}O_2P$ requires C, 76.2; H, 6.41; P, 8.56%), R_F 0.5, $\nu_{max.}$ 1 670 (C=O), 1 445 (P–Ph), 1 210, 1 195, and 1 180 cm^{-1}; δ($CDCl_3$) 8.25—7.1 (15 H, m, 3 × Ph), 4.35 (1 H, dd, J_{HH} 10, J_{HP} 16 Hz, CHP), 2.8 (1 H, m, $CHMe_2$), 1.15 (3 H, d, J 7 Hz, Me*), and 0.95 (3 H, d, J 7 Hz, Me*) (Found: M^+, 362.1440. $C_{23}H_{23}O_2P$ requires M, 362.1436), m/z 363 (3%, M + 1), 362 (1%), 320 (35%, M − $CHMe_2$), and 201 (100%, Ph_2PO^+).

2-*Diphenylphosphinoyl*-4-*methyl*-1-*phenylpentan*-1-*one* (**12f**; R^1 = Bu^i, R^2 = Ph).—In the same way, isopentyldiphenylphosphine oxide (**6**; R^1 = Bu^i) (8.2 g, 30 mmol), n-butyl-lithium (1.5M in hexane; 20 ml), and ethyl benzoate (2.25 g, 15 mmol) gave the *ketone* (**12f**) (4.2 g, 75.0% based on ethyl benzoate) after flash column chromatography (elution with EtOAc) as needles, m.p. 163—166 °C (from EtOAc) (Found: C, 76.4; H, 6.72; P, 8.28. $C_{24}H_{25}O_2P$ requires C, 76.6; H, 6.71; P, 8.24%), R_F 0.4, $\nu_{max.}$ 1 670 (C=O), 1 440 (P–Ph), and 1 185 cm^{-1} (P=O); δ($CDCl_3$) 8.0—7.2 (15 H, m, 3 × Ph), 4.65 (1 H, ddd, J_{HH} 3, 11, J_{HP} 16 Hz, CHP), 2.5—2.15 (1 H, m, $CHMe_2$), 1.9—1.4 (2 H, m, CH_2), 0.9 (3 H, d, J_{HMe} 6 Hz, Me*), and 0.8 (3 H, d, J_{HMe} 6 Hz, Me*) (Found: M^+, 376.1565. $C_{24}H_{25}O_2P$ requires M, 376.1592), m/z 377 (3%, M + 1), 376 (7%), 320 (48%, M − CH_2CHMe_2), 201 (63%, Ph_2PO^+), and 105 (100%, $PhCO^+$).

1-*Cyclohexyl*-2-*diphenylphosphinoylpropan*-1-*one* (**12g**; R^1 = Me, R^2 = cyclohexyl).—In the same way, ethyldiphenylphosphine oxide (**6**; R^1 = Me) (4.0 g, 17 mmol), n-butyl-lithium (1.5M in hexane; 11.6 ml), and methyl cyclohexanecarboxylate (1.24 g, 8.69 mmol) gave the *ketone* (**12g**) (2.5 g, 84.2% based on the ester) after flash column chromatography (elution with EtOAc), m.p. 178—179 °C (from acetone) (Found: C, 74.2; H, 7.60; P, 9.24. $C_{21}H_{25}O_2P$ requires C, 74.1; H, 7.42; P, 9.11%), R_F 0.35, $\nu_{max.}$ 1 710 (C=O), 1 440 (P–Ph), 1 180, and 1 190 cm^{-1}; δ($CDCl_3$) 8.0—7.3 (10 H, m, Ph_2PO), 3.85 (1 H, dq, J_{HMe} 7, J_{HP} 14 Hz, CHP), 2.45 (1 H, br s, ring CH), and 1.9—0.9 (total 13 H, m overlain by dd at 1.35, J_{HMe} 7, J_{MeP} 16 Hz, Me and ring CH_2·s) (Found: M^+, 240.1583. $C_{21}H_{25}O_2P$ requires M, 340.1592), m/z 341 (9%, M + 1), 340 (44%), 230 (94%, Ph_2POEt), 202 (100%, Ph_2POH), and 201 (90%, Ph_2PO^+).

Reduction of α-Diphenylphosphinoyl Ketones

Reduction of 2-*Diphenylphosphinoyl*-1-*phenylpropan*-1-*one* (**12b**; R^1 = Me, R^2 = Ph).—*Method A.* Sodium borohydride (30 mg, 0.75 mmol) was added in one portion to a stirred solution of the ketone (**12b**) (500 mg, 1.5 mmol) in ethanol (20 ml). The reaction mixture was heated under reflux for 3 h, cooled to room temperature, and then a saturated aqueous solution of ammonium chloride (10 ml) was added. The ethanol was removed under reduced pressure and several drops of dilute HCl were added to the aqueous residues. After addition of brine (15 ml), the aqueous reaction mixture was extracted with dichloromethane (3 × 30 ml) and the combined organic extracts were dried ($MgSO_4$) and evaporated to give an oil which contained a mixture of diastereoisomers. Separation by flash column chromatography (elution with EtOAc then acetone) gave the (1*RS*, 2*SR*)-adduct *erythro*-(**11b**) (56 mg, 11.1%) and the (1*RS*, 2*RS*)-adduct *threo*-(**11b**) (447 mg, 88.9%).

Method B. Borane (0.5M as a complex in THF; 5.98 ml) was added dropwise from a syringe to a stirred solution of the ketone (**12b**) (1.0 g, 3.0 mmol) in dry THF (20 ml) at −78 °C (acetone–solid CO_2). After 30 min the reaction mixture was allowed to warm to 25 °C and stirred at this temperature for 18 h. Saturated aqueous sodium sulphate (25 ml) was then added dropwise, the THF was removed under reduced pressure, and the aqueous residues diluted with brine (30 ml). The mixture was extracted with dichloromethane (3 × 30 ml) and the combined organic extracts were washed once with 5% aqueous hydrogen peroxide, dried ($MgSO_4$), and evaporated to dryness to give the product as a mixture of diastereoisomers. Separation by flash column chromatography (elution with EtOAc then acetone) gave the (1*RS*, 2*SR*)-adduct *erythro*-(**11b**) (264 mg, 26.3%) and the (1*RS*, 2*RS*)-adduct *threo*-(**11b**) (714 mg, 71.4%).

Method C. The ketone (**12d**) (1.0 g, 3.0 mmol) was added portionwise to a stirred suspension of lithium aluminium hydride (114 mg, 3.0 mmol) in dry THF (25 ml) at 0 °C. The reaction mixture was stirred for 2 h at 25 °C before being cooled again to 0 °C and the addition, dropwise, of saturated aqueous sodium sulphate (25 ml). The THF was removed under reduced pressure and the aqueous residues diluted with brine (15 ml)

before extraction with dichloromethane (3 × 20 ml). The combined organic extracts were washed once with 5% aqueous hydrogen peroxide, dried ($MgSO_4$), and evaporated to dryness to give the product as a solid mixture of diastereoisomers. Separation by flash column chromatography (elution with EtOAc then acetone) gave the (1*RS*, 2*SR*)-adduct *erythro*-(**11b**) (434 mg, 43.4%) and the (1*RS*, 2*RS*)-adduct *threo*-(**11b**) (543 mg, 54.3%).

Method D. The ketone (**12b**) (100 mg, 0.3 mmol) was added to a stirred suspension of platinum oxide (10 mg) in methanol (10 ml) at 25 °C. The reaction mixture was stirred vigorously under an atmosphere of hydrogen (*ca.* 760 mmHg) for 24 h after which the catalyst was filtered off and the filtrate evaporated to dryness to give a colourless oil (100 mg). N.m.r. analysis showed that the product was an equal mixture of starting ketone and the (1*RS*, 2*RS*)-adduct *threo*-(**11b**).

Method E. Lithium tri-t-butoxyaluminium hydride (76 mg) and the ketone (**12b**) (100 mg, 0.3 mmol) were heated under reflux in dry toluene (20 ml) for 6 h. The reaction mixture was allowed to cool to room temperature overnight before the addition of saturated aqueous ammonium chloride (10 ml) and several drops of dilute HCl. The toluene was removed under reduced pressure and the aqueous residue diluted with brine (10 ml) before extraction with dichloromethane (3 × 15 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated to dryness to give a crystalline solid (101 mg). N.m.r. analysis showed the product was a 60 : 40 mixture of starting ketone and the (1*RS*, 2*RS*)-adduct *threo*-(**11b**).

Reduction of 2-*Diphenylphosphinoyl*-1-*phenylbutan*-1-*one* (**12c**; R^1 = Et, R^2 = Ph).—*Method A.* Sodium borohydride (18 mg, 0.48 mmol) and the ketone (**12c**) (330 mg, 0.95 mmol) gave, after flash column chromatography (elution with EtOAc then acetone), the (1*RS*, 2*SR*)-adduct *erythro*-(**11c**) (35 mg, 10.5%) and the 1*RS*, 2 *RS*)-adduct *threo*-(**11c**) (293 mg, 88.3%).

Reduction of 2-*Diphenylphosphinoyl*-1-*phenylpentan*-1-*one* (**12d**; R^1 = Pr, R^2 = Ph).—*Method A.* Sodium borohydride (84 mg, 2.21 mmol) and the ketone (**12d**) (800 mg, 2.21 mmol) gave, after flash column chromatography (elution with EtOAc then acetone), the (1*RS*, 2*SR*)-adduct *erythro*-(**11d**) (83 mg, 10.3%) and the 1*RS*, 2*RS*)-adduct *threo*-(**11d**) (703 mg, 87.3%).

Reduction of 2-*Diphenylphosphinoyl*-1-*phenylhexan*-1-*one* (**12e**; R^1 = Bu, R^2 = Ph).—*Method A.* Sodium borohydride (151 mg, 4.0 mmol) and the ketone (**12e**) (1.5 g, 4.0 mmol) gave, after flash column chromatography (elution with EtOAc), the (1*RS*, 2*SR*)-adduct *erythro*-(**11e**) (144 mg, 9.5%) and the (1*RS*, 2*RS*)-adduct *threo*-(**11e**) (1.224 g, 81.1%).

Reduction of 2-*Diphenylphosphinoyl*-3-*methyl*-1-*phenylbutan*-1-*one* (**12g**; R^1 = Pr^i, R^2 = Ph).—*Method A.* Sodium borohydride (63 mg, 1.7 mmol) and the ketone (**12g**) (600 mg, 1.7 mmol) gave, after flash column chromatography (elution with EtOAc), the (1*RS*, 2*SR*)-adduct *erythro*-(**11g**) (92 mg, 15.3%) and the (1*RS*, 2 *RS*)-adduct *threo*-(**11g**) (454 mg, 75.3%).

Reduction of 2-*Diphenylphosphinoyl*-4-*methyl*-1-*phenylpentan*-1-*one* (**12f**; R^1 = Bu^i, R^2 = Ph).—*Method A.* Sodium borohydride (151 mg, 4.0 mmol) and the ketone (**12f**) (1.5 g, 4.0 mmol) gave, after flash column chromatography (elution with EtOAc), the (1*RS*, 2*SR*)-adduct *erythro*-(**11f**) (137 mg, 9.1%) and the (1*RS*, 2*RS*)-adduct *threo*-(**11f**) (1.169 g, 77.4%).

Reduction of 1-*Cyclohexyl*-2-*diphenylphosphinoylpropan*-1-*one* (**12s**; R^1 = Me, R^2 = cyclohexyl).—*Method A.* Sodium borohydride (167 mg, 4.41 mmol) and the ketone (**12s**) (1.5 g, 4.41 mmol) gave, after flash column chromatography (elution with EtOAc), the (1*RS*, 2*SR*)-adduct *erythro*-(**11s**) (136 mg, 9.0%) and the (1*RS*, 2*RS*)-adduct *threo*-(**11s**) (1.304 g, 86.4%).

Applications of the Horner-Wittig Reaction: Isosafrole (1RS, 2SR)-2-*Diphenylphosphinoyl*-1-(3,4-*methylenedioxyphenyl*)-*propan*-1-*ol* (**11r**).—n-Butyl-lithium (1.5M in hexane; 5.8 ml) was added dropwise from a syringe to a stirred solution of ethyldiphenylphosphine oxide (**6**; R^1 = Me) (2.0 g, 8.69 mmol) in dry THF (30 ml) at 0 °C. After 30 min the red reaction solution was cooled to —78 °C (acetone–solid CO_2) and a solution of 3,4-methylenedioxybenzaldehyde (1.3 g, 8.69 mmol) in dry THF (10 ml) was added dropwise from a syringe. The rate of addition was such that the internal solution temperature was maintained at −78 °C. The orange solution was allowed to warm to room temperature over 2 h and then water (25 ml) was added. The THF was removed under reduced pressure and the aqueous residue was diluted with brine (15 ml) before extraction with dichloromethane (3 × 50 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated to dryness to give the product as a crystalline mixture of diastereoisomers which were separated by flash column chromatography (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct *erythro*-(**11r**), microcrystals (2.5 g, 75.8%), m.p. 137—140 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 69.1; H, 5.73; P, 8.01. $C_{22}H_{21}O_4P$ requires C, 69.4; H, 5.58; P, 8.15%), R_F 0.6 (blue fluorescence), $\nu_{max.}$ 3 400 (OH), 1 235 (C–O), and 1 150 cm^{-1} (P=O); δ($CDCl_3$) 8.1—7.4 10 H, m, Ph_2PO), 6.8 and 6.75 (3 H, two s, aryl Hs), 5.9 (2 H, s, OCH_2), 5.2 (1 H, dd, J_{HH} 1, J_{HP} 9 Hz, C*H*OH), 4.5 (1 H, br s, OH), 2.55 (1 H, ddq, J_{HH} 1, J_{HMe} = J_{HP} = 7 Hz, C*H*Me), and 1.05 (3 H, dd, J_{HMe} 7, J_{MeP} 17 Hz, Me) (Found: M^+, 380.1157. $C_{22}H_{21}O_4P$ requires *M*, 380.1178), *m*/*z* 380 (9%), 230 (63%, Ph_2POEt), and 202 (100%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct *threo*-(**11r**) (277 mg, 8.4%), m.p. 197—199 °C [from EtOAc–light petroleum (b.p. 40—60 °C)] (Found: C, 69.2; H, 5.55; P, 8.40. $C_{22}H_{21}O_4P$ requires C, 69.4; H, 5.58; P, 8.15%), R_F 0.45, $\nu_{max.}$ 3 275 (OH), 1 440 (P–Ph), and 1 165 cm^{-1} (P=O); δ($CDCl_3$) 8.0—7.2 (10 H, m, Ph_2PO), 6.8 and 6.65 (3 H, two s, aryl H), 5.8 (2 H, s, OCH_2), 5.55 (1 H, br d, J_{HOH} *ca.* 3 Hz, OH), 4.7 (1 H, br dd, J_{HH} = J_{HP} = 9 Hz, C*H*OH), 2.8 (1 H, ddq, J_{HMe} 7, J_{HH} = J_{HP} = 9 Hz, C*H*Me), and 0.75 (3 H, dd, J_{HMe} 7, J_{MeP} 17 Hz, Me) (Found: M^+, 380.1170, $C_{22}H_{21}O_4P$ requires *M*, 380.1177), *m*/*z* 381 (22%, *M* + 1), 380 (68%), 379 (51%, *M* − 1), 230 (76%, Ph_2POEt), 202 (100%, Ph_2POH), and 201 (92%, Ph_2PO^+).

(*Z*)-*Isosafrole* (**26**).[42]—Sodium hydride (80% dispersion in oil; 24 mg, 0.79 mmol) was added in one portion to a stirred solution of the (1*RS*,2*SR*)-phosphine oxide *erythro*-(**11r**) (300 mg, 0.79 mmol) in dry DMF (30 ml). The clear reaction solution was warmed to 50 °C for 30 min by which time a white solid had precipitated from solution. The reaction mixture was cooled and the precipitate dissolved by the addition of water (25 ml). The mixture was diluted with brine (15 ml) and extracted with Et_2O (3 × 40 ml). The combined organic extracts were washed with water (3 × 40 ml), dried ($MgSO_4$), and the solvent removed under reduced pressure. Bulb-to-bulb distillation (Kugelrohr apparatus) gave (*Z*)-isosafrole *Z*-(**4r**) (108 mg, 84.4%) as a colourless liquid, R_F 0.75 (fluorescent), $\nu_{max.}$ (liquid film) 1 500 (aryl-H), 1 450, 1 260, and 1 040 (C–O), 940, and 820 cm^{-1}; δ($CDCl_3$) 6.8 (3 H, m, aryl Hs), 6.35 (1 H, dq, J_{HMe} 2, J_{HH} 11 Hz, C*H*=CHMe), 5.95 (2 H, s, OCH_2), 5.7 (1 H, dq, J_{HMe} 7, J_{HH} 11 Hz, C*H*Me), and 1.9 (3 H, dd, J_{HMe} 2, 7 Hz, Me). G.l.c. analysis (column 4) showed that the product contained *ca.* 4% of the *E*-isomer.

3,4-*Methylenedioxybenzoic Acid*.—A solution of potassium permanganate (18 g, 0.114 mol) in water (360 ml) was added over 45 min to a mixture of 3,4-methylenedioxybenzaldehyde (12 g, 0.08 mol) and water (300 ml) stirred at 80 °C. The reaction mixture was stirred a further 1 h at 80 °C, after which 10% (w/w) aqueous potassium hydroxide (25 ml) was added and the mixture then filtered whilst hot. The filtrate was cooled to room temperature and the product was precipitated by acidification (pH 2) with concentrated HCl. The precipitate was collected and washed with water to give the acid as needles (10 g, 75.4%), m.p. 229—231 °C (from 95% EtOH) (lit.,[58] 227—228 °C), R_F 0.6, $\nu_{max.}$ 2 650—2 500 (OH) and 1 670 cm^{-1} (C=O); δ[$(CD_3)_2SO$] 12.4 (1 H, br s, OH), 7.5 (1 H, dd, J_{HH} 2, 8, Hz, aryl H), 7.25 (1 H, d, J_{HH} 2 Hz, aryl H), 6.8 (1 H, d, J_{HH} 8 Hz, aryl H), and 6.0 (2 H, s, OCH_2).

Methyl 3,4-*Methylenedioxybenzoate*.—A solution of 3,4-methylenedioxybenzoic acid (1.66 g, 0.01 mol) in methanol (40 ml) containing 5 drops of concentrated H_2SO_4 was heated under reflux for 18 h. The reaction solution was cooled to room temperature, basified with saturated aqueous sodium hydrogen carbonate, and the methanol removed under reduced pressure. The aqueous residues were diluted with water (50 ml), extracted with dichloromethane (3 × 20 ml) and the combined organic extracts dried ($MgSO_4$) and evaporated to dryness to give the ester (1.5 g, 83.3%), m.p. 49—51 °C [from light petroleum (b.p. 60—80 °C)] (lit.,[59] 51.5 °C), R_F 0.65, $\nu_{max.}$ 1 710 cm^{-1} (C=O); δ($CDCl_3$) 7.6 (1 H, dd, J_{HH} 2, 8 Hz, aryl H), 7.4 (1 H, d, J_{HH} 2 Hz, aryl H), 6.75 (1 H, d, J_{HH} 8 Hz, aryl H), 5.95 (2 H, s, OCH_2), and 3.8 (3 H, s, Me).

2-*Diphenylphosphinoyl*-1-(3,4-*methylenedioxyphenyl*)*propan*-1-*one* (**12r**).—n-Butyl-lithium (1.5M in hexane; 6.7 ml) was added dropwise from a syringe to a stirred solution of ethyldiphenylphosphine oxide (**6**; R^1 = Me) (2.3 g, 0.01 mol) in dry THF (35 ml) at 0 °C. After 30 min the red reaction solution was cooled to −78 °C (acetone–solid CO_2) and a solution of methyl 3,4-methylenedioxybenzoate (900 mg, 5 mmol) in dry THF (15 ml) was added dropwise from a syringe. The pale yellow solution was allowed to warm to room temperature before addition of water (20 ml) and removal of the THF under reduced pressure. The aqueous residues were diluted with brine (15 ml) and extracted with dichloromethane (3 × 30 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated to dryness to give an oil that crystallised with time. Flash column chromatography (elution with EtOAc–acetone, 2:1) gave the *ketone* (**12r**) as needles (1.6 g, 84.7% based on the ester), m.p. 163—165 °C (from EtOAc) (Found: C, 69.6; H, 5.16; P, 8.39. $C_{22}H_{19}O_4P$ requires C, 69.8; H, 5.07; P, 8.20%), R_F 0.35, $\nu_{max.}$ 1 765 (C=O), 1 245 (C–O), and 1 195 cm^{-1} (P=O); δ($CDCl_3$) 8.1—7.2 (12 H, m, Ph_2PO, aryl Hs), 6.7 (1 H, d, J_{HH} 8 Hz, aryl H), 5.95 (2 H, s, OCH_2), 4.5 (1 H, dq, J_{HMe} 7, J_{HP} 16 Hz, C*H*Me), and 1.5 (3 H, dd, J_{HMe} 7, J_{MeP} 16 Hz, Me) (Found: M^+, 378.1043. $C_{22}H_{19}O_4P$ requires M, 378.1021), m/z 379 (3%, M + 1), 378 (33%), 201 (45%, Ph_2PO^+), and 149 (100%, M − $Ph_2POCH_2CH_2$).

Reduction of the α-*Diphenylphosphinoyl Ketone* (**12r**).—Sodium borohydride (110 mg, 2.91 mmol) was added in one portion to a stirred solution of the ketone (**12r**) (1.1 g, 2.91 mmol) in ethanol (30 ml). The reaction mixture was heated under reflux for 3 h, cooled to room temperature, and then saturated aqueous ammonium chloride (15 ml) was added. The ethanol was removed under reduced pressure and several drops of dilute HCl were added to the aqueous residues. After dilution with brine (20 ml), the aqueous reaction mixture was extracted with dichloromethane (3 × 50 ml) and the combined organic extracts were dried ($MgSO_4$) and evaporated to dryness to give the product as a solid mixture of diastereoisomers. Separation by flash column chromatography (elution with EtOAc–acetone, 4:1) gave the (1*RS*, 2*SR*)-phosphine oxide *erythro*-(**11r**) (65 mg, 5.9%) and the (1*RS*, 2*RS*)-phosphine oxide *threo*-(**11r**) (1.007 g, 90.7%).

(E)-*Isosafrole* (**26**).[42]—The procedure used was the same as that described for preparing the *Z*-isomer. The (1*RS*, 2*RS*)-phosphine oxide *threo*-(**11r**) (500 mg, 1.32 mmol) and sodium hydride (80% dispersion in oil; 79 mg, 2.63 mmol) gave after distillation, (*E*)-isosafrole *E*-(**4r**) (184 mg, 86.4%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 500 (aryl-H), 1 440, 1 250 (C–O), 1 195, 1 040 (C–O), 965 (C–H out of plane def.), 940, and 785 cm^{-1}; δ($CDCl_3$) 6.8 and 6.65 (3 H, two s, aryl Hs), 6.3 (1 H, d, J_{HH} 15 Hz, C*H*=CHMe), 6.05—5.7 (total 3 H, m overlain by s at 5.8, C*H*Me and OCH_2), and 1.8 (3 H, d, J_{HMe} 5 Hz, Me). The *Z*-isomer was not detected by g.l.c. (column 4).

2-*Diphenylphosphinoyl*-1-(2-*methoxyphenyl*)*propan*-1-*ol* (**11h**; R^1 = Me, R^2 = 2-$MeOC_6H_4$).—n-Butyl-lithium (1.5M in hexane; 2.9 ml) was added from a syringe to a stirred solution of ethyldiphenylphosphine oxide (**6**; R^1 = Me) (1.0 g, 4.35 mmol) in dry THF (28 ml) at 0 °C. After 30 min the red reaction solution was cooled to −78 °C (acetone–solid CO_2) and a solution of 2-methoxybenzaldehyde (592 mg, 4.35 mmol) in dry THF (2 ml) was added dropwise from a syringe. The rate of addition was such that the internal solution temperature was maintained at −78 °C. The pale yellow solution was allowed to warm to room temperature over 2 h and then water (15 ml) was added. The THF was removed under reduced pressure and the aqueous residue was diluted with brine (50 ml) before extraction with dichloromethane (3 × 50 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated to dryness to give the product as a mixture of diastereoisomers which were separated by flash column chromatography (elution with EtOAc then acetone). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct *erythro*-(**11h**) (1.172 g, 73.7%), m.p. 147—149 °C (from EtOAc–light petroleum b.p. 60—80 °C) (Found: C, 72.4; H, 6.2; P, 8.37. $C_{22}H_{23}O_3P$ requires C, 72.1; H, 6.34; P, 8.46%), R_F 0.5, $\nu_{max.}$ 3 400 (OH), 1 600 and 1 585 (=C–H), 1 440 (P–Ph), 1 245 (C–O), and 1 175 cm^{-1} (P=O); δ($CDCl_3$) 8.2—7.4 (10 H, m, Ph_2PO), 7.3—6.7 (4 H, m, aryl H), 5.55 (1 H, d, J_{HP} 10 Hz, C*H*OH), 4.6 (1 H, s, OH), 3.7 (3 H, s, OMe), 2.85 (1 H, dq, J_{HMe} = J_{HP} = 7 Hz, C*H*Me), and 1.0 (3 H, dd, J_{HMe} 7, J_{MeP} 16 Hz, CHMe) (Found: M^+, 366.1371. $C_{22}H_{23}O_3P$ requires M, 366.1385), m/z 366 (12%), 230 (100%, Ph_2POEt), and 202 (57%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct *threo*-(**11h**) (278 mg, 17.5%), m.p. 109—112 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 72.0; H, 6.33; P, 8.56. $C_{22}H_{23}O_3P$ requires C, 72.1; H, 6.34; P, 8.46%), R_F 0.4, $\nu_{max.}$ 3 270 (OH), 1 605, and 1 590 (=C–H), 1 440 (P–Ph), 1 250 (C–O), and 1 175 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.2 (10 H, m, Ph_2PO), 7.2—6.6 (4 H, m, aryl H), 5.25 (1 H, dd, J_{HH} 7, J_{HP} 16 Hz, C*H*OH), 5.0 (1 H, br s, OH), 3.75 (3 H, s, OMe), 3.15 (1 H, ddq, J_{HH} = J_{HMe} = J_{HP} = 7 Hz, C*H*Me), and 1.0 (3 H, dd, J_{HMe} 7, J_{MeP} 17 Hz, CHMe) (Found: M^+, 366.1372. $C_{22}H_{23}O_3P$ requires M, 366.1385), m/z 366 (12%), 230 (100%, Ph_2POEt), and 202 (46%, Ph_2POH).

(Z)-1-(2-*Methoxyphenyl*)*prop*-1-*ene* *Z*-(**4h**; R^1 = Me, R^2 = 2-$MeOC_6H_4$).[60]—The (1*RS*, 2*SR*)-adduct *erythro*-(**11h**) (119 mg, 0.324 mmol) was added in one portion to a stirred solution of potassium hydroxide (85% pure; 21 mg, 0.324 mmol) in dry DMSO (10 ml). The reaction solution was heated for 1 h at 50 °C and then cooled to room temperature before addition of water (15 ml) and brine (10 ml). The mixture was extracted with Et_2O (3 × 20 ml), and the combined organic extracts were

washed with water (3 × 20 ml), dried ($MgSO_4$), and then evaporated under reduced pressure. Bulb-to-bulb distillation (Kugelrohr apparatus) gave the alkene *Z*-(**4h**) (40 mg, 83.3%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 603 and 1 580 (=C–H), 1 490, 1 465, 1 240, and 1 030 (C–O), and 755 cm^{-1}; δ(CCl_4) 7.2—6.65 (4 H, m, aryl H), 6.4 (1 H, dq, J_{HMe} 2, J_{HH} 11 Hz, C*H*=CHMe), 5.65 (1 H, dq, J_{HMe} 7, J_{HH} 11 Hz, C*H*Me), 3.75 (3 H, s, OMe), and 1.75 (3 H, dd, J_{HMe} 2, 7 Hz, CHMe). G.l.c. analysis (column 1) showed that the product contained *ca.* 2% of the *E*-isomer.

(E)-1-(2-*Methoxyphenyl*)*prop*-1-*ene* *E*-(**4h**; R^1 = Me, R^2 = 2-$MeOC_6H_4$).[60]—In the same way, the (1*RS*, 2*RS*)-adduct *threo*-(**11h**) (119 mg, 0.324 mmol) and potassium hydroxide (85% pure; 21 mg, 0.324 mmol) gave after distillation, the alkene *E*-(**4h**) (43 mg, 89.6%) as a colourless liquid, R_F 0.75 $\nu_{max.}$ (liquid film) 1 600 (=C–H), 1 490, 1 460, 1 240, and 1 030 (C–O), 970 (C–H) out of plane def.), and 750 cm^{-1}; δ(CCl_4) 7.3—6.5 (5 H, m, aryl H and C*H*=CHMe), 6.05 (1 H, dq, J_{HMe} 7, J_{HH} 16 Hz, C*H*Me), 3.75 (3 H, s, OMe), and 1.85 (3 H, dd, J_{HMe} 2, 7 Hz, CHMe).[61] G.l.c. analysis (column 1) showed that the product contained *ca.* 3% of the *Z*-isomer.

2-*Diphenylphosphinoyl*-1-(3-*methoxyphenyl*)*propan*-1-*ol* (**11i**; R^1 = Me, R^2 = 3-$MeOC_6H_4$).—In the same way, ethyldiphenylphosphine oxide (**6**; R^1 = Me) (1.0 g, 4.35 mmol), n-butyl-lithium (1.5M in hexane; 2.9 ml) and 3-methoxybenzaldehyde (592 mg, 4.35 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography (elution with EtOAc then acetone). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct *erythro*-(**11i**) (1.090 g, 68.6%), m.p. 138—139 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 72.2; H, 6.04; P, 8.60. $C_{22}H_{23}O_3P$ requires C, 72.1; H, 6.34; P, 8.46%), R_F 0.45, $\nu_{max.}$ 3 300 (OH), 1 440 (P–Ph), 1 280 (C–O), 1 160 (P=O), and 1035 cm^{-1} (C–O); δ($CDCl_3$) 8.1—7.4 (10 H, m, Ph_2PO), 7.3—6.65 (4 H, m, aryl H), 5.2 (1 H, d, J_{HP} 9 Hz, C*H*OH), 4.6 (1 H, s, OH), 3.75 (3 H, s, OMe), 2.55 (1 H, dq, J_{HMe} = J_{HP} = 7 Hz, C*H*Me), and 1.0 (3 H, dd, J_{HMe} 7, J_{HP} 16 Hz, CH*Me*) (Found: M^+, 366.1377. $C_{22}H_{23}O_3P$ requires *M*, 366.1385), *m*/*z* 366 (3%), 230 (83%, Ph_2POEt) and 202 (100%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct *threo*-(**11i**) (270 mg, 17.0%), m.p. 154—156 °C (from EtOAc–light petroleum b.p. 60—80 °C) (Found: C, 71.8; H, 6.5; P, 8.4. $C_{22}H_{23}O_3P$ requires C, 72.1; H, 6.34; P, 8.46%), R_F 0.35, $\nu_{max.}$ 3 210 (OH), 1 435 (P–Ph), 1 250 (C–O), and 1 165 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.35 (10 H, m, Ph_2PO), 7.25—6.65 (4 H, m, aryl H), 5.6 (1 H, d, J_{HOH} 2 Hz, OH), 4.8 (1 H, dt, J_{HOH} 2, J_{HH} = J_{HP} = 9 Hz, C*H*OH), 3.75 (3 H, s, OMe), 2.9 (1 H, ddq, J_{HMe} 7, J_{HH} = J_{HP} = 9 Hz, C*H*Me), and 0.75 (3 H, dd, J_{HMe} 7, J_{MeP} 17 Hz, Me) (Found: M^+, 366.1374. $C_{22}H_{23}O_3P$ requires *M*, 366.1385), *m*/*z* 366 (5%), 230 (100%, Ph_2POEt), and 202 (36%, Ph_2POH).

(Z)-1-(3-*Methoxyphenyl*)*prop*-1-*ene* *Z*-(**4i**; R^1 = Me, R^2 = 3-$MeOC_6H_4$).—In the same way, the (1*RS*, 2*SR*)-adduct *erythro*-(**11i**) (119 mg, 0.324 mmol) and potassium hydroxide (85% pure; 21 mg, 0.324 mmol) gave after distillation, the alkene *Z*-(**4i**) (41 mg, 85.4%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 600 and 1 580 (=C–H), 1 260, 1 160, and 1 050 (C–O), 790 and 700 cm^{-1}; δ(CCl_4) 7.2—6.5 (4 H, m, aryl H), 6.3 (1 H dq, J_{HMe} 2, J_{HH} 12 Hz, C*H*=CHMe), 5.65 (1 H, dq, J_{HMe} 7, J_{HH} 12 Hz, C*H*Me), 3.7 (3 H, s, OMe), and 1.85 (3 H, dd, J_{HMe} 2, 7 Hz, CH*Me*). G.l.c. analysis (column 1) showed that the product contained *ca.* 5% of the *E*-isomer.

(E)-1-(3-*Methoxyphenyl*)*prop*-1-*ene* *E*-(**4i**; R^1 = Me, R^2 = 3-$MeOC_6H_4$).—In the same way, the (1*RS*, 2*RS*)-adduct *threo*-(**11i**) (119 mg, 0.324 mmol) and potassium hydroxide (85% pure; 21 mg, 0.324 mmol) gave after distillation, the alkene *E*-(**4i**) (42 mg, 87.5%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 600 and 1 580 (=C–H), 1 490, 1 430, 1 260, 1 250, 1 150, and 1 040 (C–O) 960 (C–H) out of plane def.), 770, and 685 cm^{-1}; δ(CCl_4) 7.15—6.5 (4 H, m, aryl H), 6.3 (1 H, d, J_{HH} 16 Hz, C*H*=CHMe), 6.1 (1 H, dq, J_{HMe} 5, J_{HH} 16 Hz, C*H*Me), 3.7 (3 H, s, OMe), and 1.8 (3 H, d, J_{HMe} 5 Hz, CH*Me*). The *Z*-isomer was not detected by g.l.c. (column 1).

2-*Diphenylphosphinoyl*-1-(4-*methoxyphenyl*)*propan*-1-*ol* (**11j**; R^1 = Me, R^2 = $MeOC_6H_4$).—In the same way, ethyldiphenylphosphine oxide (**6**; R^1 = Me) (1.0 g, 4.35 mmol), n-butyl-lithium (1.5M in hexane; 2.9 ml) and 4-methoxybenzaldehyde (592 mg, 4.35 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography (elution with EtOAc then acetone). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct *erythro*-(**11j**) (1.280 g, 80.5%), m.p. 150—151 °C (from EtOAc) (Found: C, 71.9; H, 6.38; P, 8.70. $C_{22}H_{23}O_3P$ requires C, 72.1; H, 6.33; P, 8.47%), R_F 0.5, $\nu_{max.}$ 3 430 (OH), 1 510 (aryl-H), 1 440 (P–Ph), 1 240 (C–O), and 1 160 cm^{-1} (P=O); δ($CDCl_3$) 8.05—7.3 (10 H, m, Ph_2PO), 7.2 (2 H, d, J_{HH} 9 Hz, aryl Hs), 6.8 (2 H, d, J_{HH} 9 Hz, aryl H), 5.25 (1 H, d, J_{HP} 9 Hz, C*H*OH), 4.7 (1 H, br s, OH), 3.75 (3 H, s, OMe), 2.6 (1 H, dq, J_{HMe} = J_{HP} = 7 Hz, C*H*Me), and 1.05 (3 H, dd, J_{HMe} 7, J_{MeP} 16 Hz, CH*Me*) (Found: M^+, 366.1386. $C_{22}H_{23}O_3P$ requires *M*, 366.1385), *m*/*z* 367 (19%, *M* + 1), 366 (68%), 348 (63%, *M* − H_2O), 230 (100%, Ph_2POEt), and 202 (98%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct *threo*-(**11j**) (186 mg, 11.7%), m.p. 149—150 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 72.0; H, 6.37; P, 8.56. $C_{22}H_{23}O_3P$ requires C, 72.1; H, 6.33; P, 8.47%), R_F 0.4, $\nu_{max.}$ 3 300 (OH), 1 510 (aryl-H), 1 440 (P–Ph), 1 240 (C–O), and 1 170 cm^{-1} (P=O); δ($CDCl_3$) 7.9—7.4 (10 H, m, Ph_2PO), 7.25 (2 H, d, J_{HH} 9 Hz, aryl Hs), 6.8 (2 H, d, J_{HH} 9 Hz, aryl H), 4.8 (1 H, dd, J_{HH} = J_{HP} = 9 Hz, C*H*Me), 4.0 (1 H, br s, OH), 3.75 (3 H, s, OMe), 2.95 (1 H, ddq, J_{HMe} 7, J_{HH} = J_{HP} = 9 Hz, C*H*Me), and 0.8 (3 H, dd, J_{HMe} 7, J_{MeP} 17 Hz, CHMe) (Found: M^+, 366.1390. $C_{22}H_{23}O_3P$ requires *M*, 366.1385), *m*/*z* 366 (18%), 348 (42%, *M* − H_2O), 230 (100%, Ph_2POEt), and 202 (53%, Ph_2POH).

(Z)-1-(4-*Methoxyphenyl*)*prop*-1-*ene* (*Z*-*Anethole*) *Z*-(**4j**; R^1 = Me, R^2 = 4-$MeOC_6H_4$).—In the same way, the (1*RS*, 2*SR*)-adduct *erythro*-(**11j**) (119 mg, 0.324 mmol) and potassium hydroxide (85% pure; 21 mg, 0.324 mmol) gave after distillation, the alkene *Z*-(**11j**) (36 mg, 75.0%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 600 (C=H), 1 240, 1 170, and 1 025 (C–O), and 830 cm^{-1}; δ(CCl_4) 7.1 (2 H, d, J_{HH} 8 Hz, aryl H), 6.7 (2 H, d, J_{HH} 11 Hz, aryl H), 6.25 (1 H, dq, J_{HMe} 2, J_{HH} 11 Hz, C*H*=CHMe), 5.55 (1 H, dq, J_{HMe} 7, J_{HH} 11 Hz, C*H*Me), 3.7 (3 H, s, OMe), and 1.8 (3 H, dd, J_{HMe} 2, 7 Hz, CHMe).[53] G.l.c. analysis (column 1) showed that the product contained *ca.* 6% of the *E*-isomer.

2-*Diphenylphosphinoyl*-1-(4-*methoxyphenyl*)*propan*-1-*one* (**12j**).—n-Butyl-lithium (1.5M in hexane; 11.6 ml) was added dropwise from a syringe to a stirred solution of ethyldiphenylphosphine oxide (**6**; R^1 = Me) (4.0 g, 0.017 mol) in dry THF (20 ml) at 0 °C. After 30 min the red reaction solution was cooled to − 78 °C (acetone–solid CO_2) and a solution of methyl 4-methoxybenzoate (2.9 g, 0.017 mol) in dry THF (15 ml) was added dropwise from a syringe. The pale yellow solution was allowed to warm to room temperature before addition of water (20 ml) and removal of the THF under reduced pressure. The aqueous residues were diluted with brine (15 ml) and extracted with dichloromethane (3 × 30 ml). The combined organic

extracts were dried ($MgSO_4$) and evaporated to dryness to give the *ketone* (**12j**) as needles (5.0 g, 79.4%), m.p. 157—159 °C (from EtOAc–Et_2O) (Found: C, 72.4; H, 5.70; P, 8.62. $C_{22}H_{21}O_3P$ requires C, 72.5; H, 5.82, P, 8.51%), R_F 0.3, $\nu_{max.}$ 1 655 (C=O), 1 600 (aryl-H), 1 435 (P–Ph), and 1 175 cm^{-1} (P=O); $\delta(CDCl_3)$ 8.1—7.2 (total 12 H, m overlain by d at 7.8, J_{HH} 8 Hz, Ph_2PO and aryl Hs), 6.75 (2 H, d, J_{HH} 8 Hz, aryl H), 4.45 (1 H, dq, J_{HMe} 7, J_{HP} 16 Hz, C*H*Me), 3.75 (3 H, s, OMe), and 1.45 (3 H, dd, J_{HMe} 7, J_{MeP} 16 Hz, CH*Me*) (Found: M^+, 364.1228. $C_{22}H_{21}O_3P$ requires *M*, 364.1228), *m/z* 365 (3%, *M* + 1), 364 (16%), 202 (22%, Ph_2POH), 201 (30%, Ph_2PO^+), and 135 (100%, $C_8H_7O_2$).

Reduction of the α-Ketophosphine Oxide (**12j**).—Sodium borohydride (156 mg, 4.12 mmol) was added in one portion to a stirred solution of the ketone (**12j**) (1.5 g, 4.12 mmol) in ethanol (10 ml). The reaction mixture was heated under reflux for 3 h, cooled to room temperature, and then saturated aqueous ammonium chloride (15 ml) was added. The ethanol was removed under reduced pressure and several drops of dilute HCl were added to the aqueous residues. After dilution with brine (20 ml), the aqueous reaction mixture was extracted with dichloromethane (3 × 50 ml), and the combined organic extracts were dried ($MgSO_4$) and evaporated to dryness to give the product as a solid mixture of diastereoisomers. Separation by flash column chromatography (elution with EtOAc then acetone) gave the (1*RS*, 2*SR*)-phosphine oxide *erythro*-(**11j**) (150 mg, 9.9%) and the (1*RS*, 2*RS*)-phosphine oxide *threo*-(**11j**) (1.350 g, 89.4%).

(E)-1-(4-*Methoxyphenyl*)*prop*-1-*ene E*-(**4j**; R^1 = Me, R^2 = 4-$MeOC_6H_4$) (E-*Anethole*).[62]—In the same way, the (1*RS*, 2*RS*)-adduct *threo*-(**11j**) (119 mg, 0.324 mmol) and potassium hydroxide (85% pure; 21 mg, 0.324 mmol) gave after distillation, the alkene *E*-(**4j**) (39 mg, 81.3%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 603 and 1 510 (=C–H), 1 280, 1 240, 1 170 and 1 030 (C–O), 960 (C–H out of plane def.), 835, and 780 cm^{-1}; $\delta(CCl_4)$ 7.1 (2 H, d, J_{HH} 8 Hz, aryl H), 6.7 (2 H, d, J_{HH} 8 Hz, aryl H), 6.25 (1 H, d, J_{HH} 16 Hz, C*H*=CHMe), 5.95 (1 H, dq, J_{HMe} 6, J_{HH} 16 Hz, C*H*Me), 3.7 (3 H, s, OMe), and 1.8 (3 H, d, J_{HMe} 6 Hz, CH*Me*).[53] The *Z*-isomer was not detected by g.l.c. (column 1).

2-*Diphenylphosphinoyl*-1-(2-*methoxyphenyl*)-3-*methylbutan*-1-*ol* (**11o**; R^1 = $CHMe_2$, R^2 = 2-$MeOC_6H_4$).—In the same way, (2-methylpropyl)diphenylphosphine oxide (**6**; R^1 = Pr^i) (1.0 g, 3.87 mmol), n-butyl-lithium (1.5M in hexane; 2.6 ml), and 2-methoxybenzaldehyde (528 mg, 3.87 mmol) gave an oil which contained two *diastereoisomers* that could not be separated by column chromatography. N.m.r. analysis indicated a 66:33 ratio of (1*RS*, 2*SR*)- and (1*RS*, 2*RS*)-adducts respectively: $\delta(CDCl_3)$ 8.15—6.4 (28 H, m, Ph_2PO and aryl H), 5.75—5.45 (total 2 H, d overlain by d, *J* 9 and 24 Hz, 2 × C*H*OH), 5.1 (2 H, br s, 2 × OH), 3.8 (2 H, s, OMe), 3.75 (4 H, s, OMe), 3.0 (2 H, m, 2 × PC*H*), 2.15 (2 H, m, 2 × C*H*Me_2), 1.35 (2 H, d, *J* 7 Hz, CH*Me**), 1.2 (2 H, d, *J* 7 Hz, CH*Me**), 1.0 (4 H, d, *J* 7 Hz, CH*Me**), and 0.8 (4 H, d, *J* 7 Hz, CH*Me**).

2-*Diphenylphosphinoyl*-1-(3-*methoxyphenyl*)-3-*methylbutan*-1-*ol* (**11p**; R^1 = Pr^i, R^2 = 3-$MeOC_6H_4$).—In the same way, isobutyldiphenylphosphine oxide (**6**; R^1 = Pr^i) (1.0 g, 3.87 mmol), n-butyl-lithium (1.5M in hexane; 2.6 ml) and 3-methoxybenzaldehyde (528 mg, 3.87 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography (elution with EtOAc). The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct *erythro*-(**11p**) (853 mg, 55.9%), m.p. 162—163 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 73.3; H, 6.85; P, 7.58. $C_{24}H_{27}O_3P$ requires C, 73.1; H, 6.92; P, 7.86%), R_F 0.6, $\nu_{max.}$ 3 370 (OH), 1 440 (P–Ph), and 1160 cm^{-1} (P=O); $\delta(CDCl_3)$ 8.15—7.35 (10 H, m, Ph_2PO), 7.3—6.6 (4 H, m, aryl Hs), 5.3 (1 H, dd, J_{HH}, 1, J_{HP} 10 Hz, C*H*OH), 4.55 (1 H, br s, OH), 3.75 (3 H, s, OMe), 2.6 (1 H, dt, J_{HH} 1, 1, J_{HP} 9 Hz, CHP), 2.2 (1 H, m, C*H*Me_2), 1.0 (3 H, d, J_{HMe} 7 Hz, CH*Me**), and 0.75 (3 H, d, J_{HMe} 7 Hz, CH*Me**) (Found: M^+, 394.1691. $C_{24}H_{27}O_3P$ requires *M*, 394.1698), *m/z* 394 (3%), 258 (40%, $Ph_2POCH_2CHMe_2$), 243 [100%, $Ph_2PO(CH_2)_3^+$], and 202 (70%, Ph_2POH). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct *threo*-(**11p**) (438 mg, 28.7%), m.p. 145—146 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 72.9; H, 6.95; P, 8.15. $C_{24}H_{27}O_3P$ requires C, 73.1; H, 6.92; P, 7.86%), R_F 0.5, $\nu_{max.}$ 3 280 (OH), 1 440 (P–Ph), and 1 145 cm^{-1} (P=O); $\delta(CDCl_3)$ 7.85—7.1 (10 H, m, Ph_2PO), 7.1—6.35 (4 H, m, aryl H), 5.35 (1 H, dd, J_{HH} *ca.* 3, J_{HP} 22 Hz, C*H*OH), 3.6 (3 H, s, OMe), 2.65 (1 H, dt, J_{HH} 3, 3, J_{HP} 10 Hz, CHP), 2.05 (1 H, m, C*H*Me_2), 1.25 (3 H, d, J_{HMe} 7 Hz, CH*Me**), and 1.1 (3 H, d, J_{HMe} 7 Hz, CH*Me**) (Found: M^+, 394.1709. $C_{24}H_{27}O_3P$ requires *M*, 394.1698), *m/z* 394 (2%), 258 (60%, $Ph_2POCH_2CHMe_2$), 243 [100%, $Ph_2PO(CH_2)_3^+$], and 202 (37%, Ph_2POH).

(Z)-1-(3-*Methoxyphenyl*)-3-*methylbut*-1-*ene Z*-(**4p**; R^1 = Pr^i, R^2 = 3-$MeOC_6H_4$).—In the same way, the (1*RS*, 2*SR*)-adduct *erythro*-(**11p**) (120 mg, 0.304 mmol) and potassium hydroxide (85% pure; 20 mg, 0.304 mmol) gave after distillation, the alkene *Z*-(**4p**) (40 mg, 74.1%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 605 and 1 580 (=C–H), 1 495, 1 475, 1 440, 1 290, 1 270, 1 160, and 1 060 (C–O), 800, and 710 cm^{-1}; $\delta(CCl_4)$ 7.2—6.55 (4 H, m, aryl H), 6.2 (1 H, d, J_{HH} 11 Hz, C*H*=CHCH), 5.35 (1 H, dd, J_{HH} 10, 11 Hz, =C*H*CH), 3.75 (3 H, s, OMe), 2.85 (1 H, m, C*H*Me_2), and 1.0 (6 H, d, J_{HMe} 7 Hz, CHMe_2). G.l.c. analysis (column 1) showed that the product contained *ca.* 3% of the *E*-isomer.

(E)-1-(3-*Methoxyphenyl*)-3-*methylbut*-1-*ene E*-(**4p**; R^1 = Pr^i, R^2 = 3-$MeOC_6H_4$).—In the same way, the (1*RS*, 2*RS*)-adduct *threo*-(**11p**) (120 mg, 0.304 mmol) and potassium hydroxide (85% pure; 20 mg, 0.304 mmol) gave after distillation, the alkene *E*-(**4p**) (48 mg, 88.9%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 600 and 1 580 (=C–H), 1 460, 1 270, 1 155 and 1 045 (C–O), 970 (C–H out of plane def.), 775, and 690 cm^{-1}; $\delta(CCl_4)$ 7.15—6.5 (4 H, m, aryl H), 6.25 (1 H, d, J_{HH} 16 Hz, C*H*=CHCH), 6.1 (1 H, dd, J_{HH} 6, 16 Hz, =C*H*CH), 3.7 (3 H, s, OMe), 2.4 (1 H, d sept, J_{HH} 6, J_{HMe} 7 Hz, C*H*Me_2), and 1.05 (6 H, d, J_{HMe} 7 Hz, CHMe_2). The *Z*-isomer was not detected by g.l.c. (column 1).

2-*Diphenylphosphinoyl*-1-(4-*methoxyphenyl*)-3-*methylbutan*-1-*ol* (**11q**; R^1 = Pr^i, R^2 = 4-$MeOC_6H_4$).—In the same way, isobutyldiphenylphosphine oxide (**6**; R^1 = Pr^i) (1.0 g, 3.87 mmol), n-butyl-lithium (1.5M in hexane; 2.6 ml) and 4-methoxybenzaldehyde (527 mg, 3.87 mmol) gave an oil which contained two diastereoisomers that were separated by flash column chromatography [elution with EtOAc–light petroleum (b.p. 60—80 °C), 3:1 and then EtOAc]. The first *diastereoisomer* to be eluted from the column was the (1*RS*, 2*SR*)-adduct *erythro*-(**11q**) (955 mg, 62.5%), m.p. 154—155 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 73.1; H, 6.77; P, 7.97. $C_{24}H_{27}O_3P$ requires C, 73.1; H, 6.92; P, 7.86%), R_F 0.6, $\nu_{max.}$ 3 470 (OH), 1 510 (aryl-H), 1 440 (P–Ph), 1 245 (C–O), and 1 160 cm^{-1} (P=O); $\delta(CDCl_3)$ 8.15—7.4 (10 H, m, Ph_2PO), 7.2 (2 H, d, J_{HH} 8 Hz, aryl H), 6.8 (2 H, J_{HH} 8 Hz, aryl H), 5.3 (1 H, dd, J_{HH} 1, J_{HP} 8 Hz, C*H*OH), 4.8 (1 H, s, OH), 3.75 (3 H, s, OMe), 2.55 (1 H, dt, J_{HH} 1, 1, J_{HP} 8 Hz, CHP), 2.4—1.9 (1 H, m, C*H*Me_2), 1.0 (3 H, d, J_{HMe} 7 Hz, CH*Me**), and 0.75 (3 H, d, J_{HMe} 7 Hz, CH*Me**) (Found: M^+, 394.1693. $C_{24}H_{27}O_3P$ requires *M*, 394.1698), *m/z* 394 (2%), 258 (25%, $Ph_2POCH_2CHMe_2$), 243

[100%, $Ph_2PO(CH_2)_3^+$], 202 (22%, Ph_2POH), and 201 (18%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the column was the (1*RS*, 2*RS*)-adduct *threo*-(**11q**) (415 mg, 27.2%), m.p. 181—183 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 72.7; H, 7.06; P, 7.64. $C_{24}H_{27}O_3P$ requires C, 73.1; H, 6.92; P, 7.86%), R_F 0.5, $\nu_{max.}$ 3 175 (OH), 1 440 (P–Ph), 1 250 (C–O), and 1 140 cm^{-1} (P=O); δ($CDCl_3$) 7.85—7.1 (10 H, m, Ph_2PO), 7.05 (2 H, d, J_{HH} 8 Hz, aryl H), 6.5 (2 H, d, J_{HH} 8 Hz, aryl H), 5.65 (1 H, d, J_{HOH} 7 Hz, OH), 5.35 (1 H, ddd, J_{HH} 3, J_{HOH} 7, J_{HP} 22 Hz, C*H*OH), 3.65 (3 H, s, OMe), 2.65 (1 H, dt, J_{HH} 3, 3, J_{HP} 11 Hz, CHP), 2.0 (1 H, m, C*H*Me_2), 1.2 (3 H, d, *J* 7 Hz, CH*Me**), and 1.05 (3 H, d, *J* 7 Hz, CH*Me**) (Found: M^+, 394.1700. $C_{24}H_{27}O_3P$ requires *M*, 394.1698), *m/z* 394 (1%), 258 (33%, $Ph_2POCH_2CHMe_2$), 243 [100%, $Ph_2PO(CH_2)_3^+$], and 202 (21%, Ph_2POH).

(*Z*)-1-(4-*Methoxyphenyl*)-3-*methylbut*-1-*ene* *Z*-(**4q**; R^1 = Pr^i, R^2 = 4-$MeOC_6H_4$).—In the same way, the (1*RS*, 2*SR*)-adduct *erythro*-(**11q**) (150 mg, 0.38 mmol) and potassium hydroxide (85% pure; 25 mg, 0.38 mmol) gave after distillation, the alkene *Z*-(**4q**) (47 mg, 70.1%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 603 and 1 510 (=C–H), 1 240, 1 170, and 1 030 (C–O), and 830 cm^{-1}; δ(CCl_4) 7.05 (2 H, d, J_{HH} 8 Hz, aryl H), 6.7 (2 H, d, J_{HH} 8 Hz, aryl H), 6.1 (1 H, d, J_{HH} 11 Hz, C*H*=CHMe), 5.25 (1 H, dd, J_{HH} 10, 11 Hz, =C*H*CH), 3.7 (3 H, s, OMe), 2.8 (1 H, m, C*H*Me_2), and 1.0 (6 H, d, J_{HMe} 7 Hz, CHMe_2). G.l.c. analysis (column 1) showed that the product contained *ca.* 3% of the *E*-isomer.

(*E*)-1-(4-*Methoxyphenyl*)-3-*methylbut*-1-*ene* *E*-(**4q**; R^1 = Pr^i, R^2 = 4-$MeOC_6H_4$).—In the same way, the (1*RS*, 2*RS*)-adduct *threo*-(**11q**) (120 mg, 0.304 mmol) and potassium hydroxide (85% pure; 20 mg, 0.304 mmol) gave after distillation, the alkene *E*-(**4q**) (43 mg, 79.6%) as a colourless liquid, R_F 0.75, $\nu_{max.}$ (liquid film) 1 605 and 1 510 (=C–H), 1 245, 1 180 and 1 040 (C–O), and 970 cm^{-1} (C–H out of plane def.); δ(CCl_4) 7.1 (2 H, d, J_{HH} 8 Hz, aryl H), 6.65 (2 H, d, J_{HH} 8 Hz, aryl H), 6.2 (1 H, d, J_{HH} 16 Hz, C*H*=CHMe), 5.85 (1 H, dd, J_{HH} 6, 16 Hz, =C*H*CH), 3.7 (3 H, s, OMe), 2.4 (1 H, d sept, J_{HH} 6, J_{HMe} 7 Hz, C*H*Me_2), and 1.05 (6 H, d, J_{HMe} 7 Hz, CHMe_2). The *Z*-isomer was not detected by g.l.c. (column 1).

1-*Bromo*-3-*methylbut*-2-*ene*.—A solution of hydrogen bromide in acetic acid (45% w/v HBr; 136 ml) was added dropwise to isoprene (50 g, 0.734 mol) at 0 °C (ice–salt). After 2 days at 4 °C, the pale yellow solution was poured onto ice (400 g) and the oily product separated, dissolved in dichloromethane (100 ml), and the solution washed with water (2 × 100 ml). The organic extracts were dried ($MgSO_4$) and the solvent removed under reduced pressure to give a pale yellow oil. Distillation gave 1-bromo-3-methylbut-2-ene as a colourless liquid (70 g, 64.0%), b.p. 36—38 °C at 15 mmHg (lit.,[63] b.p. 26—33 °C at 12 mmHg), δ($CDCl_3$) 5.55 (1 H, m, =CH), 4.0 (2 H, d, *J* 8 Hz, CH_2Br), 1.8 (3 H, s, Me), and 1.75 (3 H, s, Me).

(4-*Methylpent*-3-*enyl*)*diphenylphosphine Oxide* (**28**).—n-Butyl-lithium (1.5M in hexane; 27 ml) was added dropwise from a syringe to a stirred suspension of methyldiphenylphosphine oxide (8.0 g, 0.037 mol) in dry Et_2O (110 ml). After 30 min the pale yellow suspension was cooled to −78 °C (acetone–solid CO_2) and a solution of 1-bromo-3-methylbut-2-ene (5.5 g, 0.037 mol) in dry Et_2O (10 ml) was added dropwise. The reaction mixture was allowed to warm to 20 °C and water (120 ml) was then added. The aqueous phase was separated and extracted with dichloromethane (3 × 100 ml). The combined organic extracts were dried ($MgSO_4$) and the solvent was removed under reduced pressure. Purification by flash column chromatography (elution with EtOAc) gave two products; the first compound to be eluted from the column was the dialkylated product, [4-*methyl*-1-(2-*methylbut*-2-*enyl*)*pent*-3-*enyl*)]*diphenylphosphine oxide* (1.3 g, 10.0%, m.p. 130—131 °C (from Et_2O) (Found: C, 78.3; H, 8.37; P, 8.87. $C_{23}H_{29}OP$ requires C, 78.3; H, 8.32; P, 8.80%), R_F 0.55, $\nu_{max.}$ 1 440 (P–Ph) and 1 180 cm^{-1} (P=O); δ($CDCl_3$) 7.95—7.7 (4 H, m, Ph_2PO *ortho*-protons), 7.5—7.3 (6 H, m, Ph_2PO *meta*- and *para*-protons), 5.05 (2 H, m, 2 × =CH), 2.3 [5 H, m, $PCH(CH_2)_2$], 1.55 (6 H, s, 2 × Me), and 1.45 (6 H, s, 2 × Me) (Found: M^+, 352.1953. $C_{23}H_{29}OP$ requires *M*, 352.1956), *m/z* 353 (5%, *M* + 1), 352 (15%), 283 (36%, *M* − C_5H_9), and 202 (100%, Ph_2POH). The second compound to be eluted from the column was the *phosphine oxide* (**28**) (7.1 g, 67.6%), m.p. 68—69 °C [from Et_2O–light petroleum (b.p. 40—60 °C)] (Found: C, 76.2; H, 7.48; P, 10.85. $C_{18}H_{21}OP$ requires C, 76.0; H, 7.46; P, 10.91%), R_F 0.45, $\nu_{max.}$ 1 445 (P–Ph) and 1 185 cm^{-1} (P=O); δ($CDCl_3$) 7.85—7.3 (10 H, m, Ph_2PO), 5.1 (1 H, m, =CH), 2.3 (4 H, m, 2 × CH_2), 1.65 (3 H, s, Me), and 1.55 (3 H, s, Me) (Found: M^+, 284.1340. $C_{18}H_{21}OP$ requires *M*, 284.1330), *m/z* 284 (39%), 215 (41%, $Ph_2POCH_2^+$), and 202 (100%, Ph_2POH).

4-*Methylcyclohex*-3-*ene*-1-*carbaldehyde* (**29**).—A solution of acrolein (10.5 g, 0.187 mol), isoprene (16.5 g, 0.242 mol), and hydroquinone (20 mg) was poured into a Carius tube and flushed with nitrogen. The tube was sealed and heated at 220 °C for 2.5 h. Distillation of the reaction mixture gave the aldehyde (**29**) as a colourless liquid (20.0 g, 86.2%), b.p. 69—70 °C at 17 mmHg (lit.,[64] b.p. 73—75 °C at 20 mmHg), $\nu_{max.}$ (liquid film) 2 700 (aldehyde C–H) and 1725 cm^{-1} (C=O); δ($CDCl_3$) 9.6 (1 H, s, CHO), 5.3 (1 H, br s, =CH), and 2.6—1.5 (total 10 H, m overlain by broad s at 1.65, cyclohexyl 7-H and Me).

2-*Diphenylphosphinoyl*-1-(4-*methylcyclohex*-3-*enyl*)-5-*methylhex*-4-*en*-1-*ol* (**11cc**).—n-Butyl-lithium (1.5M in hexane; 11.7 ml) was added dropwise from a syringe to a stirred solution of phosphine oxide (**28**) (5.0 g, 17.6 mmol) in dry THF (30 ml) at 0 °C. After 30 min the dark red reaction solution was cooled to —78 °C (acetone–solid CO_2) and a solution of the aldehyde (**29**) (2.18 g, 17.6 mmol) in dry THF (10 ml) was added from a syringe. The rate of addition was such that the internal solution temperature was maintained at −78 °C. The pale yellow solution was allowed to warm to room temperature (over *ca.* 1.5 h) and water (15 ml) was then added. The THF was removed under reduced pressure, the aqueous residue was diluted with brine (30 ml) and extracted with dichloromethane (3 × 30 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated to give the *adduct* (**11cc**) as a crystalline mixture of diastereoisomers which could not be separated chromatographically (5.0 g, 69.6%), m.p. 106—110 °C [from light petroleum (b.p. 60—80 °C)] (Found: C, 76.8; H, 7.95; P, 7.40. $C_{26}H_{33}O_2P$ requires C, 76.4; H, 8.16; P. 7.59%), R_F 0.6, $\nu_{max.}$ 3 370 (OH), 1 440 (P–Ph), and 1 170 cm^{-1} (P=O); δ($CDCl_3$) 8.05—7.6 (4 H, m, Ph_2PO *ortho*-protons), 7.6—7.3 (6 H, m, Ph_2PO *meta*- and *para*-protons), 5.3 (1 H, m, ring =CH), 4.9 (1 H, m, remaining =CH), 4.2 (1 H, br s, OH), 3.9—3.5 (1 H, m, C*H*OH), and 2.8—1.0 (total 19 H, m overlain by five singlets, CHP, ring CH, 4 × CH_2 and 3 × Me) (Found: M^+, 408.2220. $C_{26}H_{33}O_2P$ requires *M*, 408.2218), *m/z* 408 (30), 313 (43%, *M* − C_7H_{11}), 202 (100%, Ph_2POH), and 201 (65%, Ph_2PO^+).

Reaction of the Adduct (**11cc**) *with Sodium Hydride*.—Sodium hydride (80% dispersion in oil; 22 mg, 0.735 mmol) was added in one portion to a stirred solution of the adduct (**11cc**) (300 mg, 0.735 mmol) in dry DMF (10 ml). The clear reaction solution was stirred at 50 °C for 30 min by which time a white solid had been precipitated. The reaction mixture was cooled and the precipitate dissolved by the addition of water (25 ml) and brine (15 ml). The mixture was then extracted with Et_2O (3 × 30 ml), and the extracts were washed with water (3 × 30 ml), dried

($MgSO_4$), and the solvent removed under reduced pressure to give an oil. Bulb-to-bulb distillation (Kugelrohr apparatus) gave a colourless liquid (120 mg, 85.7%) which consisted of an approximately equal mixture of the (E)- and (Z)-1-(4-*methylcyclohex-3-enyl*)-5-*methylhexa*-1,4-*dienes*, *E*- and *Z*-(**30**) (Found: C, 88.5; H, 11.75. $C_{14}H_{22}$ requires C, 88.3; H, 11.68%), $\nu_{max.}$ (liquid film) 2 930 (C–H str.), 1 445 (C–H def.), 1 385 (Me def.), and 975 cm^{-1} (C–H out of plane def.); δ(CCl_4) 5.4—4.9 (4 H, m, 4 × =CH), 2.8—2.4 (2 H, m, =CHCH_2CH=), and 2.2—1.2 (total 16 H, m overlain by two singlets at 1.65 and 1.6, ring CH and CH_2 and 3 × Me). Both *E*- and *Z*-alkene isomers were detected by g.l.c. (column 1).

2-*Diphenylphosphinoyl*-1-(4-*methylcyclohex*-3-*enyl*)-5-*methylhex*-4-*en*-1-*one* (**12cc**).—Pyridinium dichromate (5.5 g, 0.0147 mmol) was added to a stirred solution of the phosphine oxide adduct (**11cc**) (4.0 g, 9.796 mmol) in dry DMF (15 ml). The dark reaction mixture was stirred for 18 h at room temperature, then water (100 ml) was added. The mixture was extracted with EtOAc (3 × 50 ml) and the combined organic extracts were dried ($MgSO_4$) and filtered. The filtrate was heated under reflux for 15 min with powdered carbon (400 mg), filtered through Hyflo, and the solvent removed under reduced pressure to give the *ketone* (**12cc**) probably as a mixture of diastereoisomers (3.5 g, 87.5%), m.p. 149—151 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 76.6; H, 7.5; P, 7.9. $C_{26}H_{31}O_2P$ requires C, 76.8; H, 7.71; P, 7.63%), R_F 0.6, $\nu_{max.}$ 1 700 (C=O), 1 440 (P–Ph), and 1 195 cm^{-1} (P=O); δ($CDCl_3$) 8.1—7.65 (4 H, m, Ph_2PO *ortho*-protons), 7.65—7.3 (6 H, m, Ph_2PO *meta*- and *para*-protons), 5.25 (1 H, br s, ring =CH), 4.95 (1 H, br t, *J ca.* 7 Hz, remaining =CH), 3.8 (1 H, m, CHP), and 3.0—1.3 (total 18 H, m overlain by two singlets at 1.55 and 1.45, ring CH, 4 × CH_2 and 3 × Me) (Found: M^+, 406.2059. $C_{26}H_{31}O_2P$ requires *M*, 406.2062), *m/z* 407 (5%, *M* + 1), 406 (21%), 283 (50%, *M* − $C_8H_{11}O$), 202 (100%, Ph_2POH), and 201 (59%, Ph_2PO^+).

Reduction of the Ketone (**12cc**).—Sodium borohydride (37 mg, 0.984 mmol) was added in one portion to a stirred solution of the ketone (**12cc**) (400 mg, 0.984 mmol) in ethanol (10 ml). The reaction mixture was heated under reflux for 3 h, cooled to room temperature, and then a saturated aqueous ammonium chloride (10 ml) was added. The ethanol was removed under reduced pressure and several drops of dilute HCl were added to the aqueous residue. After dilution with brine (15 ml), the aqueous reaction mixture was extracted with dichloromethane (3 × 30 ml), the combined extracts were dried ($MgSO_4$) and evaporated to give a crystalline solid. Purification by flash column chromatography (elution with EtOAc) gave the (1RS, 2RS)-*adduct threo*-(**11cc**) as needles (300 mg, 74.6%), m.p. 159—161 °C [from EtOAc–light petroleum (b.p. 60—80 °C)] (Found: C, 76.2; H, 7.9; P, 7.55. $C_{26}H_{33}O_2P$ requires C, 76.4; H, 8.16; P, 7.59%), R_F 0.6, $\nu_{max.}$ 3 360 (OH), 1 440 (P–Ph), and 1 150 cm^{-1} (P=O); δ($CDCl_3$) 8.05—7.65 (4 H, m, Ph_2PO *ortho*-protons), 7.65—7.3 (6 H, m, Ph_2PO *meta*- and *para*-protons), 5.4—4.85 (2 H, m, 2 × =CH), 4.3 (1 H, s, OH), 3.9—3.5 (1 H, br d, *J* 18 Hz, C*H*OH), and 2.8—1.2 (total 19 H, m overlain by two singlets at 1.65 and 1.5, CHP, ring CH, 4 × CH_2 and 3 × Me) (Found: M^+, 408.2208. $C_{26}H_{33}O_2P$ requires *M*, 408.2218), *m/z* 408 (23%), 313 (72%, *M* − C_7H_{11}), 202 (100%, Ph_2POH), and 201 (64%, Ph_2PO^+).

(E)-1-(4-*Methylcyclohex*-3-*enyl*)-5-*methylhexa*-1,4-*diene E*-(**30**).—The adduct *threo*-(**11cc**) (120 mg, 0.294 mmol) and sodium hydride (80% dispersion in oil; 9 mg, 0.294 mmol) gave the E-*alkene E*-(**30**) as a colourless liquid (55 mg, 98.2%), b.p. *ca.* 90 °C at 0.15 mmHg, $\nu_{max.}$ (liquid film) 2 930 (C–H str.), 1 445 (C–H def.), 1 385 (Me def.), and 975 cm^{-1} (C–H out of plane def.); δ(CCl_4) 5.3 (3 H, m, 3 × =CH), 5.1 (1 H, br t, *J* 6 Hz, C*H*=CMe_2), 2.65 (2 H, m, =CHCH_2CH=), and 2.25—1.5 (total 16 H, m overlain by two singlets at 1.7 and 1.6, ring CH and CH_2's and 3 × Me) (Found: M^+, 190.1722. $C_{14}H_{22}$ requires *M*, 190.1722), *m/z* 190 (22%) and 79 (100%). The *Z*-isomer was not detected by g.l.c. (column 1).

1-*Cyclohexyl*-1-*diphenylphosphinoylpropan*-2-*ol* (**11aa**; R^1 = cyclohexyl, R^2 = Me).—n-Butyl-lithium (1.5M in hexane; 2.2 ml) was added dropwise from a syringe to a stirred solution of (cyclohexylmethyl)diphenylphosphine oxide (**6**; R^1 = cyclohexyl) (1.0 g, 3.35 mmol) in dry THF (30 ml) at 0 °C. After 30 min the red reaction solution was cooled to −78 °C (acetone–solid CO_2) and acetaldehyde (162 mg, 3.685 mmol) was added from a syringe. The rate of addition was such that the internal solution temperature was maintained at −78 °C. The pale yellow reaction solution was allowed to warm to 25 °C and then water (20 ml) was added. The THF was removed under reduced pressure and the aqueous residue was diluted with brine (15 ml) and extracted with dichloromethane (3 × 30 ml). The combined organic extracts were dried ($MgSO_4$) and evaporated to give the *adduct* (**11aa**) as a crystalline mixture of diastereoisomers (1.0 g, 87.0%) which could not be separated chromatographically, m.p. 197—200 °C (from EtOAc) (Found: C, 73.3; H, 8.05; P, 8.97. $C_{21}H_{27}O_2P$ requires C, 73.6; H, 7.97; P, 9.06%), R_F 0.4, δ($CDCl_3$) 8.0—7.3 (10 H, m, Ph_2PO), 4.6—4.1 (2 H, m, CHOH), and 2.45—0.8 (total 15 H, m overlain by two doublets at 1.25 and 1.15, PCH, cyclohexyl and Me) (Found: M^+, 342.1745. $C_{21}H_{27}O_2P$ requires *M*, 342.1749), *m/z* 343 (2%, *M* + 1), 342 (9%), 298 (100%, $Ph_2POC_7H_{13}$), 202 (59%, Ph_2POH), and 201 (50%, Ph_2PO^+).

3-*Diphenylphosphinoyl*-5-*phenylpentan*-2-*ol* [**11z**; R^1 = $(CH_2)_2Ph$, R^2 = Me].—In the same way, diphenyl-3-phenylpropylphosphine oxide [**6**; R^1 = $(CH_2)_2Ph$] (2.0 g, 6.246 mmol), n-butyl-lithium (1.5M in hexane; 4.2 ml) and acetaldehyde (303 mg, 6.87 mmol) gave a mixture of diastereoisomers which were separated by flash column chromatography (elution with EtOAc and then acetone). The first *diastereoisomer* to be eluted from the column *erythro*-(**11z**) (1.271 g, 55.7%) was obtained as needles, m.p. 147—148 °C (from EtOAc) (Found: C, 75.8; H, 7.03; P, 8.83. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.93; P, 8.51%), R_F 0.45, $\nu_{max.}$ 3 470 (OH) and 1 160 cm^{-1} (P=O); δ($CDCl_3$) 8.0—7.6 (4 H, m, Ph_2PO *ortho*-protons), 7.6—7.4 (6 H, m, Ph_2PO *meta*- and *para*-protons), 7.3—7.1 (3 H, m, ArH), 7.0—6.8 (2 H, m, ArH), 4.35 (1 H, dq, J_{HMe} 6, J_{HP} 12 Hz, C*H*OH), 4.15 (1 H, s, OH), 2.6—1.65 [5 H, m, PC*H*(CH_2)$_2$], and 1.2 (3 H, d, *J* 6 Hz, Me) (Found: M^+, 364.1609. $C_{23}H_{25}O_2P$ requires *M*, 364.1592), *m/z* 364 (19%), 229 [100%, $Ph_2PO(CH_2)_2^+$], 202 (25%, Ph_2POH), and 201 (34%, Ph_2PO^+). The second *diastereoisomer* to be eluted from the column *threo*-(**11z**) (896 mg, 39.3%) was obtained as needles, m.p. 189—191 °C (from acetone) (Found: C, 75.9; H, 7.07; P, 8.67. $C_{23}H_{25}O_2P$ requires C, 75.8; H, 6.93; P, 8.51%), R_F 0.35, $\nu_{max.}$ 3 320 (OH), 1 440 (P–Ph), and 1 175 cm^{-1} (P=O); δ($CDCl_3$) 7.85—7.35 (10 H, m, Ph_2PO), 7.3—7.1 (3 H, m, ArH), 7.0—6.8 (2 H, m, ArH), 4.45—4.0 (1 H, m, C*H*OH), 3.95 (1 H, s, OH), 2.9—2.3 (3 H, m, C*H*P and PhCH_2), 2.2—1.6 (2 H, m, CHCH_2), and 1.3 (3 H, d, *J* 7 Hz, Me) (Found: M^+, 364.1597. $C_{23}H_{25}O_2P$ requires *M*, 364.1592), *m/z* 364 (12%), 229 [100%, $Ph_2PO(CH_2)_2^+$], 202 (28%, Ph_2POH), and 201 (33%, Ph_2PO^+).

(Z)-5-*Phenylpent*-2-*ene Z*-[**4z**; R^1 = $(CH_2)_2Ph$, R^2 = Me].[65]—Sodium hydride (80% dispersion in oil; 26 mg, 0.879 mmol) was added in one portion to a stirred solution of the HRf isomer of adduct *erythro*-(**11z**) (320 mg, 0.879 mmol) in dry DMF (25 ml). The reaction solution was stirred at 50 °C for 30 min before being cooled and diluted with water (25 ml). The

mixture was then diluted with brine (15 ml) and extracted with Et_2O (3 × 40 ml). The combined extracts were washed with water (3 × 40 ml), dried ($MgSO_4$) and the solvent removed under reduced pressure. Bulb-to-bulb distillation (Kugelrohr apparatus) gave the *Z*-alkene *Z*-(**4z**) as a colourless liquid (103 mg, 80.5%), R_F 0.75, $\nu_{max.}$ (liquid film) 1 603 and 1 500 (=C–H), 1 450 and 700 cm^{-1} (C–H out of plane def.); $\delta(CDCl_3)$ 7.15 (5 H, m, Ph), 5.4 (2 H, m, CH=CH), 2.75—2.5 (2 H, m, PhCH_2), 2.5—2.2 (2 H, m, CH_2CH=), and 1.5 (3 H, d, *J* 6 Hz, Me). G.l.c. analysis (column 6) showed the product to contain *ca.* 2.5% of the *E*-isomer.

(E)-5-*Phenylpent*-2-*ene* *E*-[**4z**; $R^1 = (CH_2)_2Ph$, R^2 = Me].[65]—In the same way, the adduct *threo*-(**4z**) (320 mg, 8.79 mmol) and sodium hydride (80% dispersion in oil; 26 mg, 0.879 mmol) gave after distillation, the *E*-alkene *E*-(**4z**) as a colourless liquid (97 mg, 75.8%), R_F 0.75, $\nu_{max.}$ (liquid film) 1 603 and 1 500 (=C–H), 1 450, 965 (C–H out of plane def.), and 700 cm^{-1}; $\delta(CDCl_3)$ 7.2 (5 H, m, Ph), 5.45 (2 H, m, CH=CH), 2.8—2.55 (2 H, m, PhCH_2), 2.45—2.15 (2 H, m, CH_2CH=), and 1.65 (3 H, m, Me). G.l.c. analysis (column 6) showed the product to contain *ca.* 0.5% of the *Z*-isomer.

Acknowledgements

We thank Glaxo Group Research and S.E.R.C. for a CASE award and Dr Barry Price for many helpful discussions.

References

1 H. J. Bestmann and O. Vostrowsky, *Top. Curr. Chem.*, 1983, **109**, 85.
2 H. Pommer and P. C. Thieme, *Top Curr. Chem.*, 1983, **109**, 165.
3 I. Gosney and A. G. Rowley in 'Organophosphorus Reagents in Organic Synthesis,' ed. J. I. G. Cadogan, Academic Press, London, 1979, pp. 17—154.
4 L. D. Bergelson and M. M. Shemyakin, *Pure Appl. Chem.*, 1964, **9**, 271.
5 M. Schlosser, *Top. Stereochem.*, 1970, **5**, 1.
6 R. J. Anderson and C. A. Henrick, *J. Am. Chem. Soc.*, 1975, **97**, 4327.
7 C. A. Henrick, *Tetrahedron*, 1977, **33**, 1845.
8 A. S. Arora and I. K. Ugi, 'Methoden der Organischen Chemie' (Houben-Weyl), Thieme, Stuttgart, 1972, vol. V/1b, p. 728—945.
9 J. F. Normant and A. Alexakis, *Synthesis*, 1981, 841; H. C. Brown, H. D. Lee, and S. U. Kulkarni, *ibid.*, 1982, 195; H. C. Brown and D. Basaviah, *J. Org. Chem.*, 1982, **47**, 3806; H. C. Brown, D. Basaviah, and S. U. Kulkarni, *ibid.*, 3808.
10 Preliminary communications: A. D. Buss and S. Warren, *J. Chem. Soc., Chem. Commun.*, 1981, 100; *Tetrahedron Lett.*, 1983, **24**, 3911.
11 E. J. Corey and G. T. Kwiatkowsky, *J. Am. Chem. Soc.*, 1968, **90**, 6816.
12 E. J. Corey and D. E. Cane, *J. Org. Chem.*, 1969, **34**, 3053.
13 L. Horner, H. Hoffmann, H. G. Wippel, and G. Klahre, *Chem. Ber.*, 1959, **92**, 2499; L. Horner, H. Hoffmann, W. Klink, H. Ertel, and V. G. Toscano, *ibid.*, 1962, **95**, 581.
14 A. D. Buss, S. Warren, J. S. Leake, and G. H. Whitham, *J. Chem. Soc., Perkin Trans. 1*, 1983, 2215.
15 L. Horner and W. Klink, *Tetrahedron Lett.*, 1964, 2467.
16 A. J. Bridges and G. H. Whitham, *J. Chem. Soc., Perkin Trans. 1*, 1974, 142; P. F. Newton and G. H. Whitham, *J. Chem. Soc., Perkin Trans. 1*, 1979, 3067, 3072, 3077.
17 A. H. Davidson and S. Warren, *J. Chem. Soc., Chem. Commun.*, 1975, 14; *Perkin Trans. 1*, 1976, 639.
18 A. H. Davidson and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1977, 639.
19 A. H. Davidson, I. Fleming, J. I. Grayson, A. Pearce, R. L. Snowden, and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1977, 550.
20 L. Horner and H. Winkler, unpublished work, cited in L. Horner, *Pure Appl. Chem.*, 1964, **9**, 225, see p. 239.
21 A. D. Buss, W. B. Cruse, O. Kennard, and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1984, 243.
22 L. D. Bergelson, V. A. Vaver, L. I. Barsukov, and M. M. Shemyakin, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1966, 506; M. Schlosser and H. B. Thuong, *Chimia*, 1976, **30**, 197.
23 J. M. Clough and G. Pattenden, *Tetrahedron Lett.*, 1978, 4159; 1979, 5043.
24 J. I. Grayson and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1977, 2263.
25 A. Loupy, K. Sozadji, and J. Seyden-Penne, *Synthesis*, 1977, 126.
26 J. M. Muchowski and M. C. Venuti, *J. Org. Chem.*, 1981, **46**, 459.
27 C. Earnshaw, C. J. Wallis, and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1979, 3099.
28 W. C. Still, M. Kahn, and A. Mitra, *J. Org. Chem.*, 1978, **43**, 2923.
29 H. Sakurai and F. Kondo, *J. Organomet. Chem.*, 1976, **117**, 149; B. J. Barker, J. Rosenfarb, and J. A. Caruso, *Angew. Chem., Int. Ed. Engl.*, 1979, **18**, 503.
30 C. Earnshaw, J. I. Grayson, and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1979, 1506.
31 Preliminary communication: A. D. Buss, R. Mason, and S. Warren, *Tetrahedron Lett.*, 1983, **24**, 5293.
32 R. S. Torr and S. Warren, *J. Chem. Soc. Pak.*, 1979, **1**, 15.
33 F. Allen, O. Kennard, L. Nassimbeni, R. Shepherd, and S. Warren, *J. Chem. Soc., Perkin Trans. 2*, 1974, 1530.
34 D. Howells and S. Warren, *J. Chem. Soc., Perkin Trans. 2*, 1974, 992.
35 P. Brownbridge, E. Egert, P. G. Hunt, O. Kennard, and S. Warren, *J. Chem. Soc., Perkin Trans. 1*, 1981, 2751.
36 M. Cherest, H. Felkin, and N. Prudent, *Tetrahedron Lett.*, 1968, 2199.
37 N. T. Anh and O. Eisenstein, *Nouv. J. Chem.*, 1977, **1**, 61; N. T. Anh, *Top. Curr. Chem.*, 1980, **88**, 145.
38 A. D. Buss, N. Greeves, D. Levin, P. Wallace, and S. Warren, *Tetrahedron Lett.*, 1984, **25**, 357.
39 C. A. Cornish and S. Warren, *Tetrahedron Lett.*, 1983, **24**, 2603.
40 D. Levin and S. Warren, *Tetrahedron Lett.*, 1985, **26**, 505.
41 B. Lythgoe, T. A. Moran, M. E. N. Nambudiry, and S. Ruston, *J. Chem. Soc., Perkin Trans. 1*, 1976, 2386; B. Lythgoe, T. A. Moran, M. E. N. Nambudiry, T. Tideswell, and P. W. Wright, *ibid.*, 1978, 590.
42 S. Cabiddu, A. Maccioni, and M. Secci, *Ann. Chim. (Rome)*, 1962, **52**, 1261 (*Chem. Abstr.*, 1963, **59**, 489g).
43 G. Büchi and C.-P. Mak, *J. Am. Chem. Soc.*, 1977, **99**, 8073; G. Büchi and P.-S. Chu, *J. Org. Chem.*, 1978, **43**, 3717; C.-P. Mak and G. Büchi, *ibid.*, 1981, **46**, 1.
44 L. Horner, H. Hoffmann, and H. G. Wippel, *Chem. Ber.*, 1958, **91**, 64; K. Sasse, Houben-Weyl, 'Methoden der Organischen Chemie,' Thieme, Stuttgart, 1963, vol. 12/1, pp. 144—150; G. M. Kosolapoff and L. Maier, 'Organic Phosphorus Compounds,' Wiley-Interscience, New York, 1972, vol. 3, Chapter 5, pp. 349—354.
45 S. Trippett, *J. Chem. Soc.*, 1961, 2813.
46 D. C. Morrison, *J. Am. Chem. Soc.*, 1950, **72**, 4820.
47 A. Michaelis and H. v. Soden, *Liebigs Ann. Chem.*, 1885, **229**, 295.
48 A. E. Arbuzov and K. V. Nikonorov, *Zh. Obsch. Khim.*, 1948, **18**, 2008 (*Chem. Abstr.*, 1949, **43**, 3802b).
49 R. S. Davidson, R. A. Sheldon, and S. Trippett, *J. Chem. Soc. C*, 1966, 722.
50 I. Shahak and Y. Sasson, *Synthesis*, 1974, 358.
51 G. M. Underwood, A. K. Chan, T. Green, C. T. Watts, and C. A. Kingsbury, *J. Org. Chem.*, 1973, **38**, 2735.
52 K. Yasufuku, S. Hirose, S. Nozakura, and S. Murahashi, *Bull. Chem. Soc. Jpn.*, 1967, **40**, 2139.
53 M. Delmas, Y. Le Bigot, A. Gaset, and J. P. Gorrichon, *Synth. Commun.*, 1981, **11**, 125.
54 H. Umezaki, Y. Fujiwara, K. Sawara, and S. Teranishi, *Bull. Chem. Soc. Jpn.*, 1973, **46**, 2230.
55 R. Mantione, *C.R. Hebd. Seances Acad. Sci., Ser. C*, 1967, **264**, 1668.
56 H. C. Brown and S. K. Gupta, *J. Am. Chem. Soc.*, 1975, **97**, 5249.
57 G. Gelli, A. Maccioni, M. Secci, and V. Solinas, *Ann. Chim. (Rome)*, 1964, **54**, 1143 (*Chem. Abstr.*, 1965, **63**, 4190b).
58 R. L. Shriner and A. Berger, *Org. Synth.*, Coll. Vol. III, 786.
59 A. R. van Linge, *Recl. Trav. Chim. Pays-Bas*, 1897, **16**, 44.
60 N. Miyamoto and H. Nozaki, *Tetrahedron*, 1973, **29**, 3819.
61 D. C. Wigfield and K. Taymaz, *Tetrahedron Lett.*, 1973, 4841.
62 R. J. De Pasquale, *Synth. Commun.*, 1980, **10**, 225.
63 H. Staudinger, W. Kreis, and W. Schilt, *Helv. Chim. Acta*, 1922, **5**, 743 (*Chem. Abstr.*, 1923, **17**, 2974).
64 I. N. Nazarov, G. P. Kugatova, and G. A. Laumenskas, *Zh. Obshch. Khim.*, 1957, **27**, 2450 (*Chem. Abstr.*, 1958, **52**, 7171i).
65 R. A. Benkeser and C. A. Tincher, *J. Org. Chem.*, 1968, **33**, 2727; J. K. Crandall and A. C. Clark, *ibid.*, 1972, **37**, 4236; A. J. Pearson, *Tetrahedron Lett.*, 1975, 3617.

Received 8*th February* 1985; *Paper* 5/226