Asymmetric Epoxidation and Kinetic Resolution of Allylic Phosphine Oxides

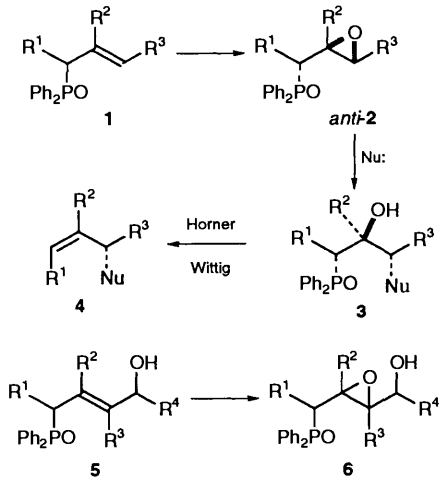
Jonathan Clayden and Stuart Warren *
University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW, UK

Allylic alcohols bearing a diphenylphosphinoyl group undergo asymmetric epoxidation with excellent enantioselectivity, and can undergo kinetic resolution with good diastereoselectivity, with the diphenylphosphinoyl group exerting an *anti*-directing effect on the epoxidation.

We are currently using diphenylphosphinoyl-substituted epoxides **2** as synthetic intermediates in the stereocontrolled synthesis of allylically and homoallylically substituted alkenes **4**.[1] Nucleophilic opening of the epoxide **2** gives the Horner–Wittig intermediate **3** which can be stereospecifically collapsed to the alkene **4**. The stereospecificity of both the epoxide opening and the Horner–Wittig elimination steps means that the stereochemistry of **4** is controlled by the relative and absolute stereochemistry of the epoxide **2**.

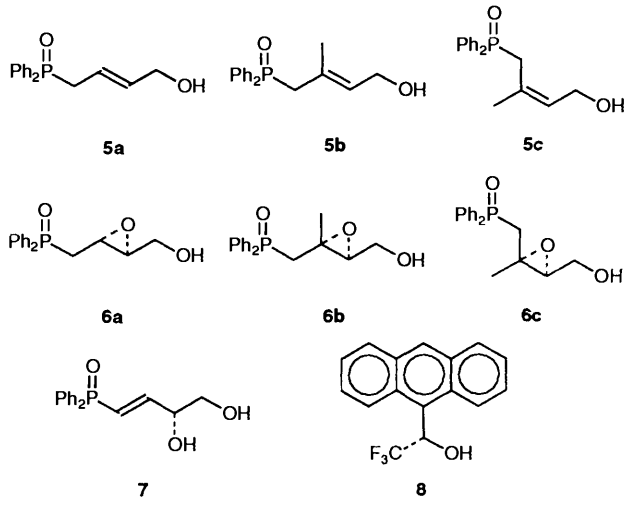
We have recently described[2,1b,1c] the synthesis of racemic diphenylphosphinoyl epoxides **2** by the diastereoselective peracid epoxidation of allylic phosphine oxides **1**. We showed that, while the epoxidation of allylic phosphine oxides with *m*-CPBA is generally *anti* selective,† the presence of a δ hydroxyl group [R^4 = CH(OH)R] can reverse this selectivity, especially if R^1 is large.

We now report[3] the asymmetric synthesis of the epoxides **6** from the allylic phosphine oxides **5** using the enantio- and diastereo-selective Sharpless epoxidation,[4] both in simple, achiral cases (R^1 = R^4 = H) and in cases requiring a kinetic resolution (R^1 or R^4 ≠ H). In the case of R^1 ≠ H, R^4 = H, we have discovered a remarkable, and, to our knowledge, unique



example of an effective Sharpless kinetic resolution of a chiral centre *trans* to the allylic hydroxymethyl group. When R^1 is large, these kinetic resolutions display an *anti* selectivity that is usefully complementary to the *syn* selectivity evident in peracid epoxidations[2,1b,1c] of the same compounds.

The achiral δ-hydroxy allylic phosphine oxides **5a–c** were available by acid-[5] or palladium(II)-catalysed[6] allylic rearrangement. They were each asymmetrically epoxidised under the conditions shown in Table 1 to give the epoxy alcohols **6a–c** in high yield and enantiomeric excess. The sense of the asymmetric induction in these reactions was inferred from precedent,[7] and enantiomeric excesses were determined by formation of Mosher's esters[8] or by 400 MHz ^{1}H NMR in the presence of 1–5 equivalents of Pirkle's chiral solvating agent, (*R*)-1-(9-anthryl)-2,2,2-trifluoroethanol **8**.[9] The reactions were slightly more successful with stoichiometric (entries 1–3) rather than catalytic[4c] (entries 5 and 6) quantities of catalyst, especially for **5c** which, as usual for hindered *Z* allylic alcohols,[7] reacted rather slowly. After epoxidation of **5a**, it was necessary to avoid the basic conditions used to hydrolyse the tartrate ester in the standard[4c] work-up: these caused rearrangement of the sensitive epoxy alcohol **6a** to the vinylic phosphine oxide **7** (entry 4). For this, and most subsequent epoxidations of allylic



phosphine oxides, we separated the product epoxy alcohols from the tartrate esters by chromatography.

Although for epoxidation of **5a** the yield and enantiomeric excess were somewhat lower than those reported[4c] for similar reactions, these results showed that allylic phosphine oxides were successful epoxidation substrates. Neither the bulk of the diphenylphosphinoyl group, nor the potential coordination of titanium(IV) by the phosphoryl group, posed a problem.

The three δ-hydroxy allylic phosphine oxides **5d–f** are secondary allylic alcohols, each with one chiral centre, and were therefore chosen as suitable substrates for Sharpless kinetic resolution.[4b,c] They were treated with *tert*-butyl hydroperoxide (0.5 equiv.), titanium tetraisopropoxide (0.5 equiv.) and L-(+)-diisopropyl tartrate (0.6 equiv.) (Scheme 1). The reactions were allowed to continue for 7–14 days at −16 °C before being quenched with water. Extent of reaction (% completion) was then determined by integration of the NMR spectrum of the crude product mixture. The components of the mixture were separated by a combination of flash chromatography and

† We use the terms *anti* and *syn* as defined by Masamune: S. Masamune, S. A. Ali, D. L. Snitman and D. S. Garvey, *Angew Chem., Int. Ed. Engl.*, 1980, 557.

Table 1 Asymmetric epoxidation of achiral allylic phosphine oxides

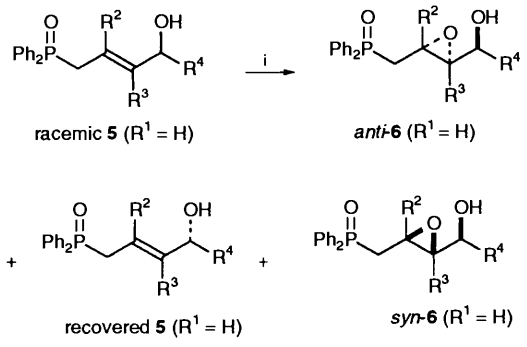
Entry	Starting material	Reagents[a]	Temp. (°C)	Time (h)	Product	Yield (%)	e.e. (%)
1	**5a**	A	−16	23	**6a**	76	82
2	**5b**	A, B	−20	1	**6b**	91	>95
3	**5c**	A, B	−18	22	**6c**	85	92
4	**5a**	A, B	−16	23	**7**	63	*b*
5	**5b**	C	−20	6	**6b**	82	97
6	**5c**	C	−17	65	**6c**	75	75–80

[a] Reagents: A: $Ti(OPr^i)_4$ (1.0 equiv.), L-(+)-DET (1.2 equiv.), Bu^tOOH (2.0 equiv.); B: NaOH, H_2O, CH_2Cl_2; C: $Ti(OPr^i)_4$ (0.10 equiv.), L-(+)-DET (0.12 equiv.), Bu^tOOH (2.0 equiv.). [b] Not determined.

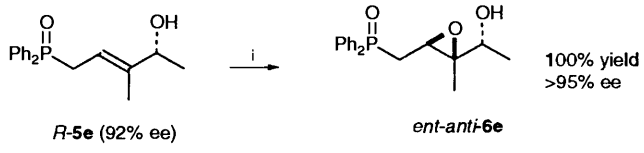
Table 2 Kinetic resolution of diphenylphosphinoyl secondary allylic alcohols

Starting material	R^1	R^2	R^3	R^4	Completion (%)	ratio **6** *anti*:*syn*	*anti*-**6** e.e. (%)	Recovered **5** e.e. (%)
5d	H	H	H	Me	50	100:0	>95	95
5e	H	H	Me	Me	50	100:0	>95	92
5f	H	Me	H	Pentyl	55	40:60	*a*	80

[a] Not determined.



Scheme 1 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-diisopropyl tartrate (0.6 equiv.), Bu^tOOH (0.5 equiv.), −16 °C, 7–14 days



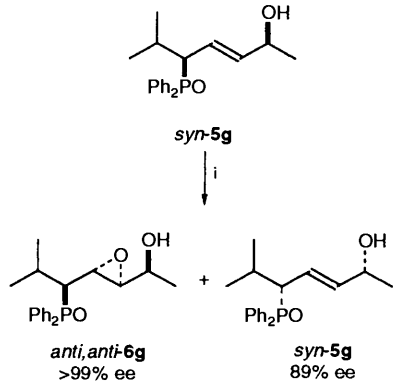
Scheme 2 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), D-(−)-diisopropyl tartrate (0.6 equiv.), Bu^tOOH (2.4 equiv.), −16 °C, 9 h

HPLC, and enantiomeric excesses were determined either by formation of Mosher's esters[8] or by 400 MHz ^1H NMR in the presence of Pirkle's reagent **8**.[9] The relative stereochemistries of the epoxides **6** were inferred from precedent[7] and by comparison with the compounds produced by peracid epoxidation of the same starting materials.[1b,2a] Table 2 shows the results of these experiments.

All three kinetic resolutions were highly enantiospecific, as judged by the enantiomeric excess of the remaining starting material **5**. And for the two compounds with no *cis* methyl substituent (**5d** and **5e**) the reactions were also highly diastereoselective: none of the *syn* diastereoiomer was observable in the ^1H NMR spectrum of the crude reaction product. Kinetic resolutions of allylic alcohols with a substituent *cis* to the allylic hydroxy group (**5f** is one of these) are frequently only poorly diastereoselective.[7]

The enantiomerically enriched **5e** obtained after kinetic resolution was asymmetrically epoxidised using the other enantiomer of the tartrate ester as a catalyst. A quantitative yield of *ent-anti*-**6e** was obtained in excellent enantiomeric excess (Scheme 2).

In order to make the alkenes **4** with a double bond of controlled geometry, we needed to use epoxides **2** which have a chiral centre α to phosphorus. We therefore took each of the two diastereoisomers of the δ-hydroxy allylic phosphine oxides **5g**, which were available by stereospecific palladium(II)-catalysed allylic rearrangement[6] or by 1,4-diastereoselective reduction of the enone **9**,[10] and subjected them to the conditions for kinetic resolution to find out what effect the second chiral centre would have on the epoxidation. We anticipated chiral centres β to phosphorus in later compounds by the choice of the isopropyl group R^1. The results of these two reactions are shown in Schemes 3 and 4. Enantiomeric excesses were determined by ^1H



Scheme 3 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-diisopropyl tartrate (0.6 equiv.), Bu^tOOH (0.5 equiv.), 7 days, −16 °C (52% completion)

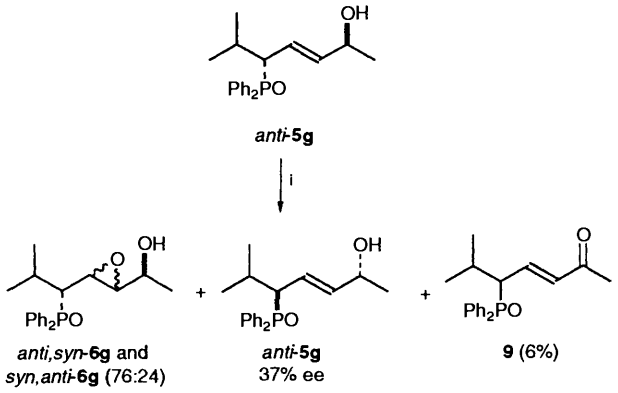
NMR spectroscopy in the presence of Pirkle's reagent **8**,[9] and the diastereoisomers identified by stereospecific conversion into alkenes[1c] and by comparison of their NMR spectra with those of compounds of known stereochemistry (for example, *anti*-**6k**).

Kinetic resolution of *syn*-**5g** was very efficient: excellent enantiomeric excesses were observed both for the epoxy alcohol *anti,anti*-**6g** and the remaining starting material *syn*-**5g** at 52% completion, and none of the *syn,syn* epoxide diastereoisomer was observed in the crude product mixture. The other diastereoisomer, *anti*-**5g**, on the other hand, behaved extremely badly

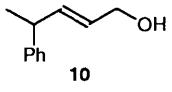
Table 3 Kinetic resolution of primary allylic alcohols with a chiral centre α to phosphorus

Starting material **5**	R^1	R^2	R^3	R^4	Completion (%)	**6** ratio *anti*:*syn*	*anti*-**6** e.e. (%)	Remaining **5** e.e. (%)
h	Me	H	H	H	56	54:46	*a*	10
i	Et	H	H	H	54	71:29	82	31
j	Pentyl	H	H	H	52	68:32	*a*	36
k	Pr^i	H	H	H	47	93:7	86	65
l	Cyclohexyl	H	H	H	44	90:10	75	63

[a] Not determined.



Scheme 4 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-diisopropyl tartrate (0.6 equiv.), Bu^tOOH (0.5 equiv.), 7 days, −16 °C (52% completion)

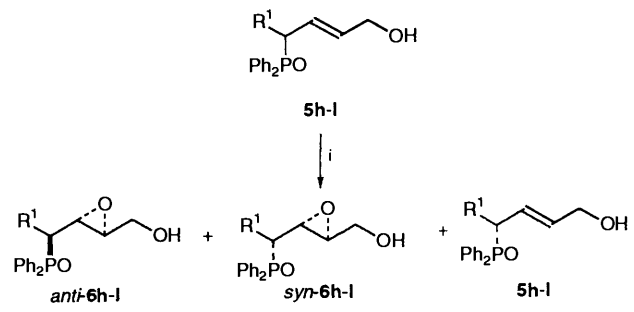


under kinetic resolution conditions. Enantiospecificity was low, with only 37% enantiomeric excess in the remaining starting material at 39% completion. The diastereoselectivity of the epoxidation was poor too: a 76:24 mixture of the two diastereoisomers *syn,anti*- and *anti,syn*-**6g** was obtained. Moreover, a significant amount of the enone **9** was formed by metal-catalysed oxidation of the allylic hydroxyl group, a side-reaction that is normally too slow to compete with epoxidation.[7a]

The powerful match/mismatch[11] effect evident in these reactions was quite unexpected. Chiral centres *trans* to the allylic hydroxyl group usually have no influence over the selectivity in a Sharpless epoxidation reaction.[12] The only published example[12a] of an attempted kinetic resolution with the chiral centre in this position is that of allylic alcohol **10**. After the epoxidation had reached 60% completion, the starting material was recovered in only 6% enantiomeric excess.

To explore this powerful effect further, we used diphenylphosphinoyl-substituted analogues of **10**, the compounds **5h–l**, which were available by palladium(II)-catalysed rearrangement.[6] These compounds, in which there is no chiral centre α to the hydroxyl group to obscure the effect of the one α to phosphorus, were subjected to the standard kinetic resolution conditions (Scheme 5). The results of the reactions are shown in Table 3. Enantiomeric excesses were measured by ^1H NMR spectroscopy in the presence of Pirkle's reagent **8**.[9]

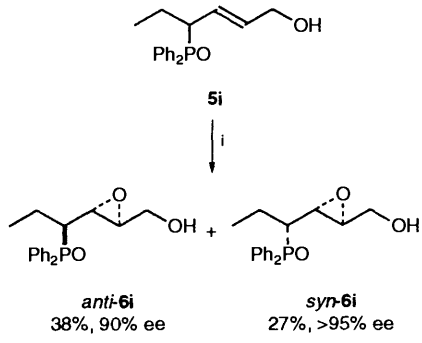
When R^1 was methyl (**5h**), the reaction proceeded very much as if the chiral centre were not there. Both enantiomers epoxidised at similar rates, and there was very little kinetic resolution, leaving starting material more or less racemic. However, with increasingly larger R^1 groups [n-alkyl substituents ethyl and pentyl (**5i** and **5j**) and β′-branched isopropyl and cyclohexyl (**5k** and **5l**)], the relative rate of epoxidation of the two enantiomers, and hence the efficiency of the kinetic



Scheme 5 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-diisopropyl tartrate (0.6 equiv.), Bu^tOOH (0.5 equiv.), 7 days, −16 °C

resolution, increased. For these last two cases (**5k** and **5l**), the chiral centre was clearly exerting a powerful influence on the course of the reaction, which gave almost solely one diastereoisomer of product in excellent enantiomeric excess, with good enantiomeric excess in the recovered starting material too.

The result for **5h** (R^1 = Me) is a very similar result to that obtained in the attempted kinetic resolution of **10**.[12a] Because both enantiomers were epoxidising at a similar rate, a more or less 1:1 mixture of the two diastereoisomers of the epoxy alcohol was obtained. For R^1 = ethyl and pentyl (**5i** and **5j**), there was a moderate difference in rates of epoxidation for the two enantiomers, indicated by moderate enantiomeric excess in the recovered starting material and the coupled moderate diastereoselectivity. When an excess of *tert*-butyl hydroperoxide was added to a similar epoxidation of **5i**, this rate difference was not sufficient to prevent epoxidation of the slow-reacting enantiomer (Scheme 6). The result of this reaction is evidence



Scheme 6 *Reagents and conditions:* $Ti(OPr^i)_4$ (0.67 equiv.), L-(+)-diisopropyl tartrate (0.85 equiv.), Bu^tOOH (2.0 equiv.)

that, even though enantiospecificity is bad, face-selectivity is good. Both diastereoisomers of **6i** had excellent enantiomeric excesses, so there can have been little 'crossing over' between the two enantiomers of the starting material and the two diastereoisomers of the product.

The success of the kinetic resolution for the branched compounds **5k** and **5l** (R^1 = Pr^i, cyclohexyl) is remarkable. There is in these reactions a 10- to 20-fold rate difference[13] for

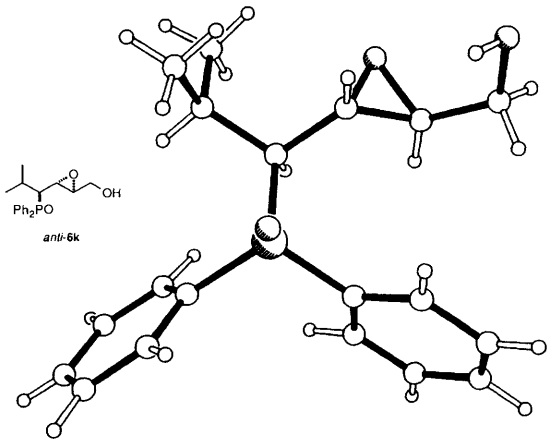
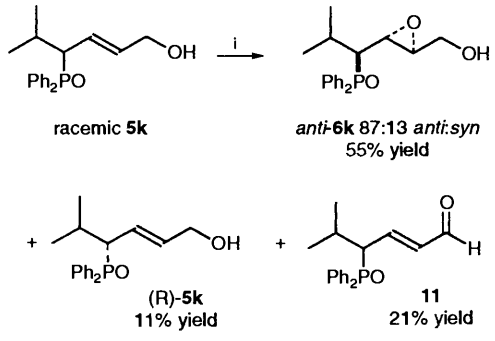


Fig. 1 X-Ray crystal structure of (2*S*,3*R*,4*S*)-4-diphenylphosphinoyl-2,3-epoxy-5-methylhexan-1-ol, *anti*-**6k**

epoxidation of the two enantiomers, making these not only the first examples of effective kinetic resolutions at a chiral centre in the remote *trans* position, but also synthetically useful reactions. The *anti* diastereoselectivity of these reactions is also usefully complementary to the *syn* diastereoselectivity of the peracid epoxidation of the same compounds.[1b,2a] We have made use of this complementarity in stereocontrolled syntheses of the stereoisomers of some unsaturated amino acids[1b] and alkenyloxazolidinones.[1c]

The isopropyl-substituted compound **5k** was also epoxidised with an excess of *tert*-butyl hydroperoxide (Scheme 7). The



Scheme 7 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.7 equiv.), L-(+)-diisopropyl tartrate (0.9 equiv.), Bu^tOOH (2.0 equiv.), (87% completion)

reaction reached 87% completion, as judged by the amount of starting material remaining in the crude product mixture (11% starting material was recovered). However, little more than a 50% yield of epoxide *syn*-**6k** was isolated. Much of the slow reacting enantiomer had undergone oxidation to the enal **11** (compare Scheme 4).

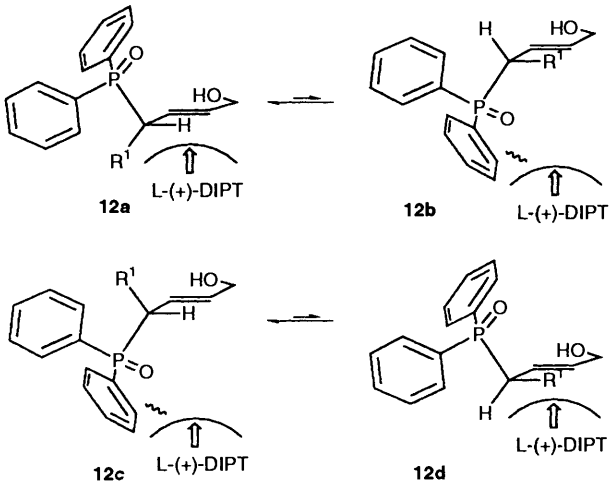
Unfortunately, separation of starting material and products from all these epoxidations could be achieved only by HPLC. Attempts to separate **5k** from *anti*-**6k** by crystallisation from various solvents were unsuccessful, with the crystals forming as 1:1 mixtures of the two compounds. The same problem beset attempts to improve the enantiomeric excess of *anti*-**6k** by crystallisation. After several recrystallisations from ethyl acetate, the enantiomeric excess had dropped to 16%.

Because of the novelty of these kinetic resolutions, the relative stereochemistry of the major epoxide products was not immediately obvious from precedent. From the co-operativity evident in the epoxidation of *syn*-**5g** we can deduce that the diphenylphosphinoyl group, like the hydroxyl group, has an *anti*-directing effect. A crystal structure,[14] shown in Fig. 1, of the major epoxide from the kinetic resolution of **5k** established that the diphenylphosphinoyl group was also directing the epoxidation of **5k** *anti*. Conversion of the remaining starting material from kinetic resolution of **5k** into a compound of reported rotation[15] allowed us to confirm that this epoxidation had the usual enantioselectivity.

It was conceivable that the size of the substituent R^1 could not only affect the efficiency of the kinetic resolution, but also change the directing effect of the diphenylphosphinoyl group (as observed with *m*-CPBA epoxidations[1b,2a]). However, all the major epoxide products, including *anti*-**6k** (whose stereochemistry was confirmed by a crystal structure) had features in the ^1H and ^{13}C NMR spectra which clearly distinguished them as a group from the minor epoxide products. The chemical shifts of the hydrogen atoms attached to carbons 1 and 2, and the coupling constant $^3J_{PC}$ between phosphorus and carbon 2, were particularly diagnostic. Table 4 summarises this data. Further confirmation of the relative stereochemistry of the epoxides **6** was provided by the stereospecific conversion of a number of them into alkenes.[1b,1c,15]

The enantiospecificity observed in the standard kinetic resolution of secondary alcohols arises from co-ordination of the hydroxyl group to the titanium centre while oxygen is delivered to the double bond. This provides a 'conformational lock' on the otherwise more or less freely rotating chiral centre. A kinetic resolution then ensues because of the greater rate of reaction when the larger of the two remaining groups is pointing away from the titanium–tartrate complex.[7]

The chiral centre bearing the diphenylphosphinoyl group is not bound in this way, so we need to consider more than one possible reactive conformation. Diagram **12a** shows the



lowest energy conformation of one enantiomer of **5** (R^2 = R^3 = R^4 = H), with H in the plane of the double bond.[16,17] As R^1 is always smaller than diphenylphosphinoyl, the next most populated conformation of this enantiomer is as shown in **12b**, with R^1 eclipsing the double bond.[17] This conformation can only be significantly populated when R^1 is small (a methyl group, for example) because of $A^{1,3}$ interactions with the *cis* vinylic hydrogen atom. Diagrams **12c** and **12d** show the same conformations for the other configuration of **5**'s chiral centre.

The inherent enantioselectivity of the asymmetric epoxidation using L-(+)-dialkyl tartrates favours delivery of the oxidant from the lower face of the double bond as shown in diagrams **12**.[7] For the conformation and configuration shown in **12a**, this means approach of the bulky titanium–tartrate–peroxide reagent alongside R^1, while for the configuration shown in **12c**, the catalyst must approach alongside the much larger diphenylphosphinoyl group. When conformations **12b** and **12d** are unpopulated (*i.e.* when R^1 is large), the outcome

Table 4 Coupling constants and chemical shifts in diphenylphosphinoyl epoxy alcohols **6** and **13**

Entry		R =	*anti* Epoxide δ_H(ppm)			J_{PC}(Hz)		*syn* Epoxide δ_H(ppm)			J_{PC}(Hz)	
			2-H	1a-H	1b-H	3-C	2-C	2-H	1a-H	1b-H	3-C	2-C
1	**6i**	Et	2.39	3.40	3.22	4.4	0	3.06	3.75	3.61	2.2	11.0
2	**6j**	Pentyl	2.39	3.40	3.23	4.4	0	3.16	3.76	3.59	2.2	10.9
3	**6k**	Pr^i	2.25	3.30	3.12	5.1	0	3.02	3.74	3.63	0	12.9
4	**6l**	Cyclohexyl	2.29	3.32	3.15	4.9	0	3.04	3.89	3.63	3.7	8.5
5	**13b**	*anti* EtCHOAc	2.40	3.37	3.21	5.3	0	3.10	3.81	3.60	0	11.3
6	**13b**	*syn* EtCHOAc	2.17	3.26	3.19	2.6	0	3.00	3.60	3.79	3.2	10.9
7	**13c**	*anti* EtCHMe	2.31	3.31	3.15	5.1	0	3.06	3.81	3.59	3.3	13.0
8	**13c**	*syn* EtCHMe	2.31	3.33	3.15	5.0	0	3.02	3.84	3.60	5.6	13.4
		Minimum value	2.17		3.12		0	3.00		3.59		8.5
		Maximum value	2.40		3.40		0	3.16		3.89		13.4

Table 5 Optimisation of the kinetic resolution

Entry	R^1OOH R^1 =	$R^2{}_2$ tartrate R^2 =	Temp. (°C)	Completion (%)	**6k** ratio *anti*:*syn*	Remaining **5k** ee (%)
1	Bu^t	Pr^i	−16	47	93:7	86
2	Bu^t	Pr^i	+4	53	92:8	71
3	Bu^t	C_6H_{11}	−16	52	92:8	77
4	Bu^t	C_6H_{11}	+4	49	89:11	78
5	Ph_3C	C_6H_{11}	−16	29	*a*	*a*
6	Ph_3C	Pr^i	+4	37	*a*	85
7	Ph_3C	C_6H_{11}	−16	—	—	—
8	Ph_3C	C_6H_{11}	+4	39	83:17	82

[a] Not determined.

of this interplay of effects is that the epoxidation of the enantiomer of **5** in **12a** is much faster than epoxidation of the enantiomer of **5** in **12b**, and an efficient kinetic resolution results. The faster reacting enantiomer of **5** gives, by this model, the observed *anti* epoxide *anti*-**6**.

If R^1 is smaller than Pr^i or cyclohexyl, the conformation of **5** depicted in **12b** and **12d** can be populated to some degree.[17] In this conformation, the relative rates of epoxidation of the two enantiomers of **5** are reversed: for the configuration in **12b**, the titanium–tartrate–peroxide reagent must approach alongside the bulky diphenylphosphinoyl group, while for the configuration in **12d** it is hindered only by a hydrogen atom. So, the more **12b** and **12d** are populated, the less efficient is the kinetic resolution. This also fits our observed trend, with **5h** (R^1 = Me) being less efficiently resolved than **5i** and **5j** (R^1 = n-alkyl), which, in turn, are less efficiently resolved than **5k** or **5l** (R^1 = sec-alkyl).

The relative rate of epoxidation of the two enantiomers of a secondary allylic alcohol is greater with bulkier dialkyl tartrates, though the absolute rate of reaction is decreased.[4c,7,18] Since the 'recognition site' for chirality in our kinetic resolutions (Table 3) is in a different region of the catalytic complex from that involved in the 'classical' kinetic resolution of secondary allylic alcohols, the effect of changing the bulk of the dialkyl tartrate, or of the alkyl hydroperoxide, might be different. A series of optimisation experiments were, therefore, performed in the hope that an alteration in the distribution of steric bulk in the epoxidation catalyst might improve the reaction. δ-Hydroxy allylic phosphine oxide **5k** was resolved kinetically (Scheme 8)

Scheme 8 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-dialkyl tartrate (0.6 equiv.), R^1OOH (0.5 equiv.)

using two dialkyl tartrates [L-(+)-diisopropyl and L-(+)-dicyclohexyl], two hydroperoxides [*tert*-butyl and triphenylmethyl] and at two temperatures (−16 °C and +4 °C). The results of these experiments are presented in Table 5.

Reactions with triphenylmethyl hydroperoxide were slow (entries 5–8). Even at +4 °C (entries 6 and 8), neither reaction reached 50% completion. And while enantioselectivity is good (entries 6 and 8), in the one case where it was measured, diastereoselectivity was worse than under the same conditions with *tert*-butyl hydroperoxide. With *tert*-butyl hydroperoxide (entries 1–4), use of dicyclohexyl tartrate seems to confer little benefit, with the results of reactions 3 and 4 being barely different from those of 1 and 2. Surprisingly, raising the temperature also seems to have little effect: the results in all of entries 1–4 are similar. Sharpless originally recommended[7a] a temperature of −20 °C in order to increase enantiomeric rate differences without slowing the absolute rates unduly. However, the best results were obtained with the standard conditions (entry 1).

δ-Hydroxy allylic phosphine oxides **5** underwent kinetic resolution most efficiently when they were branched in the β position. δ-Hydroxy allylic phosphine oxides **13a–c**, (R = OH, OAc and Me), were available by palladium(II)-catalysed allylic rearrangement.[6,1c,19] These compounds also have a β branch, and are therefore good candidates for another series of successful kinetic resolutions. Each diastereoisomer of these compounds was subjected to the standard conditions for kinetic resolution. The results of the experiments are presented in Table 6.

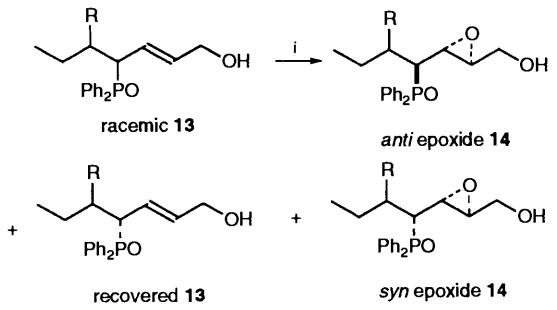
The diols **13a** (entries 1 and 2) did not react at all. We have found several examples of allylic alcohols containing a β-hydroxy phosphine oxide part structure which fail to undergo titanium(IV)-catalysed epoxidation.[15] We assume this is due to the formation of unreactive chelates **15**. The abnormal epoxidation of some 1,2-diols has been reported.[20]

The reactions in entries 3–6 were more successful. With R = Me (entries 5 and 6) the resolution was more efficient than with an acetoxy substituent. This new, and very remote, chiral centre, appears to have little influence over the reaction. The

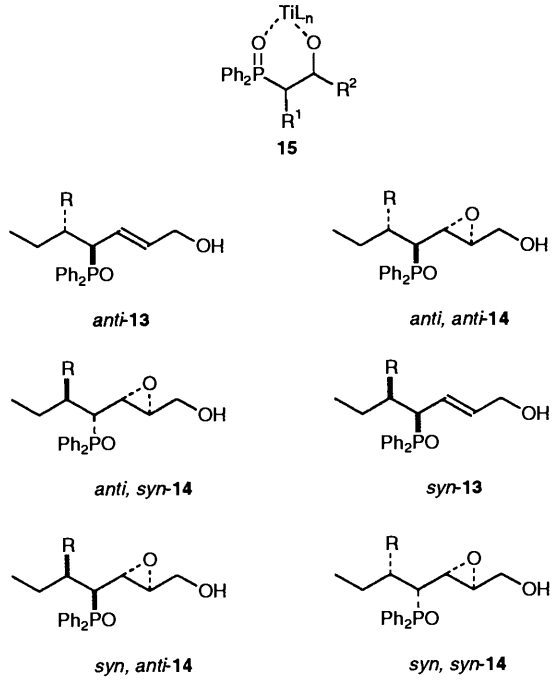
Table 6 Kinetic resolutions of compounds bearing chiral centres β to phosphorus

Entry	Starting material (SM)	R	Completion (%)	Epoxide ratio *anti*:*syn*	*anti* Epoxide ee (%)	Remaining SM ee (%)
1	*anti*-**13a**	OH	0[a]	—	—	—
2	*syn*-**13a**	OH	0[b]	—	—	—
3	*anti*-**13b**	OAc	45	86:14	87	26
4	*syn*-**13b**	OAc	45	75:25	86	42
5	*anti*-**13c**	Me	54	89:11	72	80
6	*syn*-**13c**	Me	47	91:9	70	52

[a] Starting material recovered in 93% yield. [b] Starting material recovered in 85% yield.

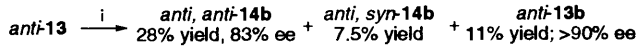


Reagents and conditions: $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-diisopropyl tartrate (0.6 equiv.), Bu'OOH (0.5 equiv.), 5 days, −16 °C

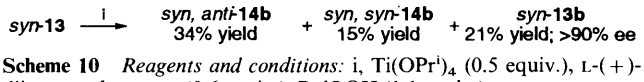


stereochemistry of the major epoxide from the kinetic resolution of *syn*-**13c** was confirmed by an X-ray crystal structure (Fig. 2).[14]

Compounds *syn*- and *anti*-**13b** were epoxidised with an excess of *tert*-butyl hydroperoxide (Schemes 9 and 10), in the hope that



Scheme 9 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-diisopropyl tartrate (0.6 equiv.), Bu'OOH (2.0 equiv.)



Scheme 10 *Reagents and conditions:* i, $Ti(OPr^i)_4$ (0.5 equiv.), L-(+)-diisopropyl tartrate (0.6 equiv.), Bu'OOH (1.1 equiv.)

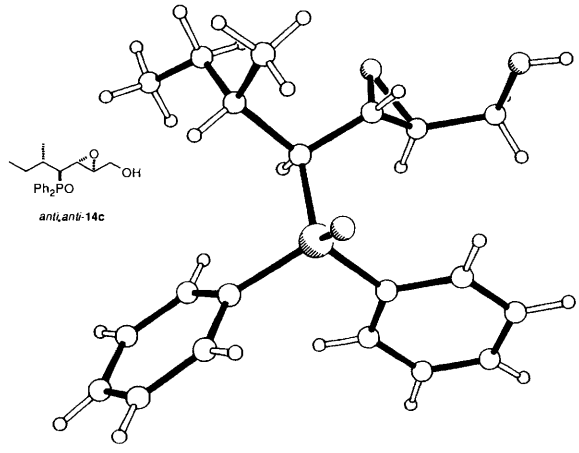


Fig. 2 X-Ray crystal structure of (2*S*,3*R*,4*S*,5*S*)-4-diphenylphosphinoyl-2,3-epoxy-5-methylheptan-1-ol, *anti-anti*-**14c**

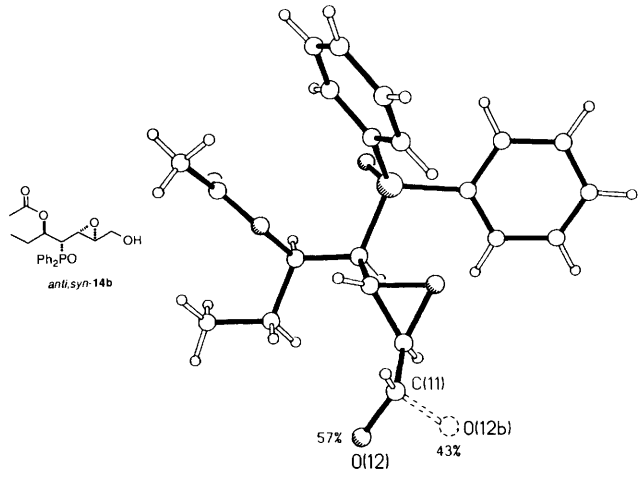


Fig. 3 X-Ray crystal structure of (2*S*,3*R*,4*R*,5*S*)-5-acetoxy-4-diphenylphosphinoyl-2,3-epoxy-5-methylheptan-1-ol, *anti-syn*-**14b**. This structure shows static disorder: the hydroxyl group occupies two positions designated O(12) (57%) and O(12b) (43%).

this would make available pure samples of all four epoxides *anti,anti*-, *anti,syn*-, *syn,anti*- and *syn,syn*-**14b**. Some starting material remained in both cases, but a sufficient quantity of the minor diastereoisomer from the epoxidation of *anti*-**13b** was available for it to be crystallised and for its relative and absolute stereochemistry to be determined by X-ray crystal structural analysis (Fig. 3).[14]

Experimental

Method A (*Asymmetric Epoxidation*).—Activated 4 Å powdered molecular sieves (*ca.* 1 g) were added to a stirred solution of the allylic alcohol (6 mmol) in dry dichloromethane (60 cm^3), and the suspension stirred under nitrogen at room

temperature for 1–3 h. Meanwhile, *tert*-butyl hydroperoxide (3.0 mol dm^{-3} solution in 2,2,4-trimethylpentane; 5 cm^3) and a solution of L-(+)-diethyl tartrate (1.484 g, 7.2 mmol, 1.2 equiv.) in dry dichloromethane (5 cm^3) were placed in separate vials over activated 4 Å powdered molecular sieves and stored for 1–3 h. The flask containing the allylic alcohol was cooled to between −16 °C and −20 °C (cooling bath or CCl_4–solid CO_2) and titanium tetraisopropoxide (1.78 cm^3, 1.70 g, 6.0 mmol, 1.0 equiv.) and then the dried solution of L-(+)-diethyl tartrate were added to it. The mixture was stirred at *ca.* −20 °C for 30–40 min after which a portion of the dried solution of *tert*-butyl hydroperoxide (4.0 cm^3, 12.0 mmol, 2.0 equiv.) was added dropwise to it and the whole stirred at *ca.* −20 °C until TLC showed completion of the reaction. Water (40 cm^3) was added to the mixture which was then stirred vigorously as it was allowed to warm to room temperature. 30% Aqueous sodium hydroxide saturated with sodium chloride (20 cm^3) was then added to the mixture, and vigorous stirring continued until the layers separated. The aqueous layer was extracted into dichloromethane or ethyl acetate (3 × 40 cm^3) and the combined organic fractions were washed with brine, dried (Na_2SO_4) and evaporated under reduced pressure to yield a crude product which was purified by flash chromatography.

Method B (*Non-basic Work-up*).—Identical in all respects with Method A, except during the work-up, which avoided addition of sodium hydroxide.

Method C (*Catalytic Asymmetric Epoxidation*).—Identical with method B, except for the quantities of titanium tetraisopropoxide and L-(+)-diethyl tartrate, which were divided by ten.

Method D (*Kinetic Resolution*).—Activated powdered 4 Å molecular sieves (*ca.* 300 mg) and L-(+)-diethyl tartrate (292 mg, 1.25 mmol, 0.6 equiv.) were added to a stirred solution of the allylic alcohol (2 mmol) in dry dichloromethane (20 cm^3), and the suspension stirred under nitrogen at room temperature for 1–3 h. Meanwhile, *tert*-butyl hydroperoxide (3.0 mol dm^{-3} solution in 2,2,4-trimethylpentane; 1 cm^3) was dried by storage over activated powdered 4 Å molecular sieves in a stoppered vial for 1–3 h. The flask containing the allylic alcohol was cooled to −16 °C (cooling bath). Titanium tetraisopropoxide (0.30 cm^3, 1.0 mmol, 0.5 equiv.) was added to the mixture which was then stirred at −16 °C for 30–40 min. A portion of the dried solution of *tert*-butyl hydroperoxide (0.35 cm^3, 1.0 mmol, 0.5 equiv.) was added dropwise to the mixture which was then stirred at −16 °C for 7–14 days. Water (20 cm^3) was added to the mixture which was then stirred vigorously as it was allowed to warm to room temperature. The aqueous layer was extracted with dichloromethane or ethyl acetate (3 × 20 cm^3) and the combined organic fractions were washed with brine, dried (Na_2SO_4) and evaporated under reduced pressure to yield a crude product.

(2S,3R)-4-*Diphenylphosphinoyl*-2,3-*epoxybutan*-1-*ol* **6a**.—By Method B, the allylic alcohol[6] **5a** (1.8527 g, 6.81 mmol) gave, after 23 h, a crude product. This was purified by flash chromatography, eluting with EtOAc and then EtOAc–5% MeOH, to yield the epoxy alcohol **6a** (1.491 g, 76%) as an oil, $[\alpha]_D^{25}$ −7.9 (*c* 1.88 in $CHCl_3$) (Found: M$^+$, 288.0890. $C_{16}H_{17}O_3P$ requires *M*, 288.0915); R_F(EtOAc) 0.10; ν_{max}($CHCl_3$)/cm^{-1} 3340 (OH), 1440 (PPh) and 1150 (P=O); δ_H(400 MHz; $CDCl_3$) 7.8–7.3 (10 H, m, Ph_2PO), 4.03 (1 H, t, *J* 6.2, OH), 3.57 (1 H, ddd, *J* 12.6, 5.1 and 3.5, CH_AH$_B$OH), 3.47 (1 H, ddd, *J* 12.6, 6.2 and 4.6, CH$_A$$H_B$OH), 3.19 (1 H, m, PCH$_2$C*H*O), 2.81 (1 H, fine m, OC*H*CH$_2$OH), 2.75 (1 H, ddd, *J* 15.1, 9.3 and 5.4, PCH_AH$_B$) and 2.34 (1 H, ddd, *J* 15.0, 13.4 and 6.9, PCH$_A$$H_B$); δ_C(100 MHz; $CDCl_3$) 133–128 (Ph_2PO), 61.3$^-$ (CH_2OH), 59.1$^+$ ($^3J_{PC}$ 5.2, OCHCH$_2$OH), 50.2$^+$ (PCH$_2$*C*HO) and 33.4$^-$ ($^1J_{PC}$ 68.0, PCH$_2$); *m*/*z* 288 (M$^+$, 3%), 270 (1.5, M − H_2O), 258 (87, M − CH_2O), 202 (100, Ph_2POH) and 201 (50, Ph_2PO). Integration of the 400 MHz ^{1}H NMR spectrum in the presence of Pirkle's chiral shift reagent showed an enantiomeric excess of 82%.

(2S,3R)-4-*Diphenylphosphinoyl*-2,3-*epoxy*-3-*methylbutan*-1-*ol* **6b**.—By Method A, the allylic alcohol[5b] **5b** (1.760 g, 6.154 mmol) gave, after 1 h at between −30 °C and −20 °C, a crude product. This was purified by flash chromatography, eluting with CH_2Cl_2–6% MeOH, to yield the *epoxy alcohol* **6b** (1.694 g, 91%) as needles, m.p. 121–125 °C (from EtOAc), $[\alpha]_D^{25}$ +4.6 (*c* 2.55 in $CHCl_3$) (Found: C, 67.7; H, 6.35; P, 10.0%; M$^+$, 302.1084. $C_{17}H_{19}O_3P$ requires C, 67.5; H, 6.35; P, 10.2%; *M*, 302.1072); R_F(EtOAc) 0.09; ν_{max}(CCl_4)/cm^{-1} 3350 (OH), 1440 (PPh) and 1180 (P=O); δ_H(250 MHz; $CDCl_3$) 7.8–7.4 (10 H, m, Ph_2PO), 3.56 (2 H, m, CH_2OH), 2.92 (1 H, dd, *J* 14.8 and 10.8, PCH_AH$_B$), 2.91 (1 H, t, *J* 5.5, OC*H*CH$_2$OH), 2.30 (1 H, dd, *J* 14.3 and *J* 12.4, PCH$_A$$H_B$) and 1.36 (3 H, s, CH_3); δ_C(100 MHz; $CDCl_3$) 134–128 (Ph_2PO), 62,7$^+$ (OCHCH$_2$OH), 60.4$^-$ (CH_2OH), 57.4 (*C*Me), 40.0$^-$ ($^1J_{PC}$ 67.4, PCH$_2$) and 16.7$^+$ (Me); *m*/*z* 302 (14%, M$^+$), 271 (85, M − CH_2OH), 202 (100, Ph_2POH) and 201 (85, Ph_2PO). Integration of the 235 MHz ^{19}F NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of >95%.

(2S,3S)-4-*Diphenylphosphinoyl*-2,3-*epoxy*-3-*methylbutan*-1-*ol* **6c**.—By Method A, the allylic alcohol[5b] **5c** (1.688 g, 5.90 mmol) gave, after 22 h, a crude product. This was purified by flash chromatography, eluting with EtOAc, to yield the *epoxy alcohol* **6c** (1.51 g, 85%) as prisms, m.p. 127–129 °C (from EtOAc), $[\alpha]_D^{25}$ −78.1 (*c* 2.18 in $CHCl_3$) (Found: C, 67.5; H, 6.35; P, 10.5%; M$^+$, 302.1055. $C_{17}H_{19}O_3P$ requires C, 67.5; H, 6.35; P, 10.2%; *M*, 302.1072); R_F(EtOAc) 0.32; ν_{max}($CHCl_3$)/cm^{-1} 3300 (OH), 1440 (PPh) and 1150 (P=O); δ_H(250 MHz; $CDCl_3$) 7.8–7.4 (10 H, m, Ph_2PO), 4.00 (1 H, dd, *J* 12.3 and 3.7, CH_AH$_B$OH), 3.43 (1 H, dd, *J* 12.3 and 9.8, CH$_A$$H_B$OH), 3.04 (1 H, dd, *J* 9.8 and 3.7, OC*H*CH$_2$OH), 2.91 (1 H, dd, *J* 16 and 6.1, PCH_AH$_B$), 2.53 (1 H, t, *J* 16, PCH$_A$$H_B$) and 0.96 (3 H, s, CH_3); δ_C(100 MHz; $CDCl_3$) 134–128 (Ph_2PO), 62.5$^+$ (OCHCH$_2$OH), 60.3$^-$ (CH_2OH), 57.4$^-$ (*C*Me), 35.2$^-$ ($^2J_{PC}$ 64.6, PCH$_2$) and 24.4$^+$ (Me); *m*/*z* 302 (6%, M$^+$), 271 (37, M − CH_2OH), 202 (77, Ph_2POH) and 201 (100, Ph_2PO). Integration of the 400 MHz ^{1}H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 92%.

One recrystallisation (from EtOAc) of this epoxy alcohol (294 mg) returned material (221 mg, 71% recovery) of which integration of the 400 MHz ^{1}H NMR spectrum of the Mosher ester indicated an enantiomeric excess of 97.5%.

Epoxidation of **5a** *with Basic Work-up*.—The allylic alcohol[6] **5a** (312 mg, 1.15 mmol), gave, by Method A, and after purification by flash chromatography, eluting with EtOAc–8% MeOH (*R*)-(*E*)-4-diphenylphosphinoylbut-3-ene-1,2-diol **7** (208 mg, 63%) as an oil, $[\alpha]_D^{25}$ +12.5 (*c* 1.18 in $CHCl_3$) (Found: M$^+$, 288.0923. $C_{16}H_{17}O_3P$ requires *M*, 288.0915); R_F (EtOAc) 0.05; ν_{max}($CHCl_3$)/cm^{-1} 3325 (OH), 1620 (C=C), 1440 (PPh) and 1150 (P=O); δ_H(400 MHz; $CDCl_3$) 7.7–7.2 (10 H, m, Ph_2PO), 6.7–6.5 (2 H, m, PCH=CH), 5.23 (1 H, d, *J* 5.2, CHO*H*), 4.66 (1 H, t, *J* 5.6, CH$_2$O*H*), 4.33 (1 H, fine m, C*H*OH), 3.61 (1 H, ddd, *J* 11.2, 5.2 and 4.1, CH_AH$_B$OH) and 3.43 (1 H, dt, *J* 11.2 and 5.6, CH$_A$$H_B$OH); δ_C(100 MHz; $CDCl_3$) 151.7$^+$ (PCH=CH), 133–128 (Ph_2PO), 121.4$^+$ ($^1J_{PC}$ 102.4, PCH), 72.9$^+$ ($^3J_{PC}$ 15.9, CHOH) and 65.6$^-$ (CH_2OH); *m*/*z* 288 (M$^+$, 4%), 270 (3, M − H_2O), 257 (61, M − CH_2OH), 215 (18, Ph_2POCH_2), 202 (100, Ph_2POH) and 201 (87, Ph_2PO).

Epoxidation of **5b** *under Catalytic Conditions*.—By Method C, the allylic alcohol[5b] **5b** (568 mg, 1.99 mmol) gave, after 6 h, the epoxy alcohol **6b** (490 mg, 82%). Integration of the 235 MHz ^{19}F NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 97%.

Epoxidation of **5c** *under Catalytic Conditions*.—By Method C, the allylic alcohol[5b] **5c** gave, after 65 h, the epoxy alcohol **6c** (870 mg, 75%). Integration of the 400 MHz ^1H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 75–80%.

Kinetic Resolution of **5d**.—By Method D, the allylic alcohol[5b,6] **5d** (575.1 mg, 2.01 mmol) gave, after 14 days, a crude product, which was purified by flash chromatography, eluting with EtOAc–5% MeOH, to yield a mixture of compounds as an oil (557.2 mg). Integration of the ^1H NMR spectrum of this material showed it to consist of a 50:50 mixture of starting material and product. Further purification by HPLC, eluting wth EtOAc–8% MeOH, gave (2*S*,3*S*,4*R*)-5-diphenylphosphinoyl-3,4-epoxypentan-2-ol *anti*-**6d** (221.45 mg, 36%) as an oil, $[\alpha]_D^{25}$ +5.4 (*c* 1.42 in $CHCl_3$), retention time 37 min (Found: M − H_2O, 284.0986. $C_{17}H_{19}O_3P$ requires *M* − H_2O, 284.0966); R_F(EtOAc) 0.11; $\nu_{max}(CHCl_3)/cm^{-1}$ 3300 (OH), 1440 (PPh) and 1150 (P=O); δ_H(400 MHz; $CDCl_3$) 7.8–7.4 (10 H, m, Ph_2PO), 3.76 (1 H, dq, *J* 3.9 and 6.4, C*H*OH), 3.27 (1 H, ddd, *J* 7.4, 5.3 and 3.2, PCH_2CHO), 2.89 (1 H, ddd, *J* 15.1, 10.6 and 4.9, PCH_AH_B), 2.81 (1 H, dd, *J* 3.7 and 2.2, OC*H*CHOH), 2.34 (1 H, ddd, *J* 14.6, 13.5 and 7.4, PCH_AH_B) and 1.07 (3 H, d, *J* 6.4, Me); δ_C(100 MHz; $CDCl_3$) 133–128 (Ph_2PO), 65.6$^+$ (CHOH), 62.2$^+$ ($^3J_{PC}$ 5.1, OCHCHOH), 50.2$^+$ (PCH_2CHO), 33.3$^-$ ($^1J_{PC}$ 68, PCH_2) and 19.0$^+$ (Me); *m*/*z* 284 (5%, M − H_2O), 257 (16, M − MeCHOH), 216 (8, Ph_2POMe), 215 (38, Ph_2POCH_2), 202 (100, Ph_2POH) and 201 (51, Ph_2PO). Integration of the 400 MHz ^1H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent showed an enantiomeric excess of >95%.

Also eluted from the HPLC machine was the starting allylic alcohol **5d** (215.0 mg, 37%), $[\alpha]_D^{25}$ −8.4 (*c* 1.86 in $CHCl_3$), retention time 45 min. Integration of the ^1H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 95%.

Kinetic Resolution of **5e**.—By Method D, the allylic alcohol[6] **5e** (615.32 mg, 2.05 mmol) gave, after 7.5 days, a crude product. Integration of the ^1H NMR spectrum of this material showed it to contain a 50:50 mixture of starting material and product. Purification by flash chromatography, eluting with EtOAc–4% MeOH gave (2*S*,3*S*,4*R*)-5-diphenylphosphinoyl-3,4-epoxy-4-methylpentan-2-ol *anti*-**6e** (201.1 mg, 31%) as an oil, $[\alpha]_D^{25}$ +0.77 (*c* 1.37 in $CHCl_3$) (Found: M − OH, 299.1200. $C_{18}H_{21}O_3P$ requires *M* − OH, 299.1201); R_F(EtOAc) 0.19; $\nu_{max}(CHCl_3)/cm^{-1}$ 3340 (OH), 1440 (PPh) and 1150 (P=O); δ_H(400 MHz; $CDCl_3$) 7.7–7.3 (10 H, m, Ph_2PO), 3.49 (1 H, q, *J* 6.3, C*H*OH), 3.37 (1 H, br s, OH), 3.30 (1 H, q, *J* 5.8, PCH_2CHO), 2.65 (1 H, ddd, *J* 15.5, 10.8 and 5.8, PCH_AH_B), 2.45 (1 H, ddd, *J* 15.5, 14.4 and 6.7, PCH_AH_B), 1.14 (3 H, s, CHC*Me*) and 1.04 (3 H, d, *J* 6.4, CH*Me*); δ_C(100 MHz; $CDCl_3$) 135–128 (Ph_2PO), 69.7$^+$ (CHOH), 63.7$^-$ ($^3J_{PC}$ 5.3, CH*C*Me), 54.8$^+$ (PCH_2CO), 30.7 ($^1J_{PC}$ 68.1, PCH_2) and 18.0 and 13.1 (2 × Me); *m*/*z* 316 (0.1%, M$^+$), 301 (2, M − Me), 298 (3, M − H_2O), 282 (3, M − H_2O − O), 272 (5, M − MeCHO), 271 (4, M − MeCHOH), 216 (15, Ph_2POMe), 215 (11, Ph_2POCH_2), 202 (100, Ph_2POH) and 201 (68, Ph_2PO). Integration of the ^1H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of >95%. Irradiation of the doublet at δ 1.04 reduced the signal at δ 3.49 to a singlet.

Also obtained from the column was the starting allylic alcohol **5e** (196.6 mg, 32%), $[\alpha]_D^{25}$ −14.3 (*c* 0.99 in $CHCl_3$). Integration of the ^1H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 92%. Mixed fractions from the column gave further material (151 mg).

Kinetic Resolution of **5f**.—By Method D, the allylic alcohol[6] **5f** (1.1312 g, 3.17 mmol) gave, after 8 days, a crude product. Integration of the ^1H NMR spectrum of this material showed it to consist of a 45:55 mixture of starting material and products. Purification by flash chromatography, eluting with EtOAc and then EtOAc–10% MeOH gave a 60:40 (by ^1H NMR) mixture of the epoxide[2] *syn*-**6f** and the *epoxide* (2*R*,3*R*,4*S*)-1-diphenylphosphinoyl-2,3-epoxy-2-methylnonan-4-ol *anti*-**6f** (537.5 mg, 46%) as an oil (Found: M$^+$, 372.1858. $C_{22}H_{29}O_3P$ requires *M*, 372.1854); R_F(EtOAc) 0.30; δ_H(400 MHz; $CDCl_3$) (peaks due to *anti*-**6f** only) 7.7–7.4 (10 H, m, Ph_2PO), 3.4–3.2 (1 H, m, C*H*OH), 2.93 (1 H, dd, *J* 14.6 and 9.1, PCH_AH_B), 2.72 (1 H, d, *J* 7.8, HOCHC*H*O), 2.29 (1 H, t, *J* 13.2, PCH_AH_B), 1.34 (3 H, s, OCMe), 1.6–0.8 [8 H, m, $(CH_2)_2$] and 0.86 (3 H, t, *J* 7.0, CH_2Me); δ_C(100 MHz; $CDCl_3$) (peaks due to *anti*-**6f** only) 134–128 (Ph_2PO), 69.3$^+$ (CHOH), 65.3$^+$ ($^3J_{PC}$ 2.9, HOCH*C*HO), 57.2$^-$ (Me*C*O), 40.3$^-$ ($^1J_{PC}$ 66.6, PCH_2), 35.1$^-$ (HOCH*C*H_2), 31.8$^-$ (HOCHCH$_2$*C*H_2), 24.6$^-$ (*C*H_2CH$_2$Me), 22.5$^-$ (*C*H_2Me), 19.0$^+$ (OC*Me*) and 14.0$^+$ (CH_2Me); *m*/*z* 372 (0.5%, M$^+$), 301 (3.5, M − C_5H_{11}), 271 (30, $Ph_2POCH_2CHCHCHO$), 259 [18, Ph_2POCH_2C(OH)Me], 215 (15, Ph_2POCH_2), 202 (100, Ph_2POH) and 201 (52, Ph_2PO).

Also obtained from the column was the starting allylic alcohol **5f** (463.1 mg, 41%). Integration of the ^1H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 80%.

Asymmetric Epoxidation of the remaining Starting Material from Kinetic Resolution of **5f**.—By Method B, the allylic alcohol (*R*)-**5f** (147.85 mg, 0.49 mmol; 92% ee), with titanum tetraisopropoxide (0.15 cm^3, 0.5 mmol, 1 equiv.), D-(−)-diisopropyl tartrate (142 mg, 0.6 mmol, 1.2 equiv.) and *tert*-butyl hydroperoxide (3 mol dm^{-3} solution in 2,2,4-trimethylpentane; 0.4 cm^3, 24 equiv.) gave, after 9 h, a crude product. Purification by flash chromatography, eluting with EtOAc–10% MeOH gave (2*R*,3*R*,4*S*)-5-diphenylphosphinoyl-3,4-epoxy-4-methylpentan-2-ol *anti*-**6f** (156.3 mg, 100%) as an oil, $[\alpha]_D^{25}$ −1.4 (*c* 1.1 in $CHCl_3$). Integration of the ^1H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of >95%.

Kinetic Resolution of syn-**5g**.—By Method D, the allylic alcohol[6,10] *syn*-**5g** (438.12 mg, 1.33 mmol) gave, after 7 days, a crude product which was purified by flash chromatography, eluting with EtOAc and then EtOAc–10% MeOH, to yield a mixture of compounds (450 mg). The ^1H NMR spectrum of this material showed a 52:48 mixture of one epoxide product and starting material. Further purification by HPLC, eluting with $CHCl_3$–1.4% MeOH, gave (2*S*,3*S*,4*R*,5*S*)-5-diphenylphosphinoyl-3,4-epoxy-6-methylheptan-2-ol *anti*,*anti*-**6g** (147.1 mg, 32%) as prisms, m.p. 153–154 °C (from EtOAc), $[\alpha]_D^{25}$ −10.1 (*c* 0.67 in $CHCl_3$), retention time 7.5 min (Found: C, 69.9; H, 7.4; P, 9.1%; M$^+$, 344.1572. $C_{20}H_{25}O_3P$ requires C, 69.75; H, 7.32; P, 8.99%; *M*, 322.1541); R_F(EtOAc) 0.25; ν_{max}(Nujol)/cm^{-1} 3350 (OH), 1440 (PPh) and 1150 (P=O); δ_H(250 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.49 (1 H, dq, *J* 4.5 and 6.5, C*H*OH), 3.38 (1 H, dt, *J* 9.5 and 2, PCHC*H*O), 2.41 (1 H, dd, *J* 4.8 and 2.2, OC*H*CHOH), 2.2 (1 H, m, C*H*Me$_2$), 2.16 (1 H, dt, *J* 3 and 10, PCH), 2.05 (1 H, br s, OH), 1.19 (3 H, d, *J* 6.5, CH*Me*$_A$Me$_B$), 1.14 (3 H, d, *J* 6.5, CHMe$_A$*Me*$_B$) and 0.88

(3 H, d, *J* 6.5, CHOH*Me*); δ_C(100 MHz; $CDCl_3$) 133–128 (Ph_2PO), 65.9$^+$ (CHOH), 60.6$^+$ (O*C*HCHOH), 52,7$^+$ ($^2J_{PC}$ 5.1, PCH*C*HO), 46.6$^+$ ($^1J_{PC}$ 65.6, PCH), 27.9$^+$ (*C*HMe$_2$), 23.9$^+$ ($^3J_{PC}$ 13.2, CH*Me*$_A$Me$_B$), 18.7$^+$ ($^3J_{PC}$ 1.6, CHMe$_A$*Me*$_B$) and 18.1$^+$ (CHOH*Me*); *m/z* 344 (1.5%, M$^+$), 257 (36, $Ph_2POCHCHMe_2$), 219 (15, $Ph_2PO_2H_2$), 202 (100, Ph_2POH) and 201 (80, Ph_2PO). A heteronuclear correlation experiment confirmed the assignments in the ^{13}C NMR spectrum. Integration of the ^1H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of >99%.

Also eluted from the HPLC machine was the allylic alcohol *syn*-**5g** (160.1 mg, 37%), $[\alpha]_D^{25}$ +59.3 (*c* 0.66 in $CHCl_3$), retention time 12.5 min. Integration of the ^1H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 89%.

Kinetic Resolution of anti-**5g**.—By Method D, the allylic alcohol[6] *anti*-**5g** (666.9 mg, 2.04 mmol) gave, after 7 days, a crude product. Analytical HPLC, eluting with $CHCl_3$–2% MeOH showed that this material consisted of 61% starting material, 33% of a 76:24 mixture of epoxides[2] *syn,anti*-**6g** and *anti,syn*-**6g**, and 6% of the enone **9**.[10] Purification by preparative HPLC, eluting with $CHCl_3$–1% MeOH, gave recovered starting material *anti*-**5g** (214.2 mg, 32%), retention time 16 min. Integration of the ^1H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 37%.

Kinetic Resolution of **5h**.—By Method D, the allylic alcohol[6] **5h** (569.8 mg, 1.99 mmol) gave, after 5 days, a crude product which was purified by flash chromatography, eluting with $CHCl_3$–5% MeOH, to yield a mixture of compounds (440 mg). Investigation of this material by analytical HPLC, eluting with $CHCl_3$–2% MeOH, showed it to consist of 44% starting material **5h** plus a 54:46 mixture of epoxides[2] *anti*-**6h** and *syn*-**6h**. Further partial purification by HPLC, eluting with $CHCl_3$–3% MeOH, gave a sample of the remaining starting material **5h** (57.5 mg). Integration of the ^1H NMR spectrum of the Mosher ester of this material indicated an enantiomeric excess of 10%.

Kinetic Resolution of **5i**.—By Method D, the allylic alcohol[6] **5i** (601.5 mg, 2.00 mmol) gave, after 6 days, a crude product. Integration of the ^1H NMR spectrum of this material showed it to contain a 46:54 mixture of starting material **5i** and a 71:29 ratio of the *epoxides anti*-**6i** and *syn*-**6i**. Purification by flash chromatography, eluting with $CHCl_3$–5% MeOH, gave a mixture of compounds (540 mg), which were further purified by HPLC, eluting with $CHCl_3$–3.5% MeOH, to give (2*S*,3*R*,4*S*)-4-diphenylphosphinoyl-2,3-epoxyhexan-1-ol *anti*-**6i** (250 mg, 40%) as minute prisms, m.p. 140–141 °C (from EtOAc), $[\alpha]_D^{25}$ −54.3 (*c* 0.84 in $CHCl_3$), retention time 12.5 min (Found: C, 68.4; H, 6.7; P, 9.8%; M$^+$, 316.1226. $C_{18}H_{21}O_3P$ requires C, 68.34; H, 6.69; P, 9.79%; *M*, 316.1228); R_F(EtOAc) 0.13; ν_{max}(Nujol)/cm^{-1} 3230 (OH), 1435 (PPh) and 1180 (P=O); δ_H(250 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.40 (1 H, dd, *J* 12.5 and 2.8, C*H*$_A$H$_B$OH), 3.22 (1 H, d × fine m, *J* 9, PCHC*H*O), 3.21 (1 H, dd, *J* 12.5 and 4, CH$_A$*H*$_B$OH), 2.39 (1 H, dt, *J* 4 and 2, OC*H*CH$_2$OH), 2.1–1.8 (3 H, m, PCHCH$_2$) and 1.10 (3 H, t, *J* 7.5, Me); δ_C(100 MHz; $CDCl_3$) 132–128 (Ph_2PO), 61.3$^-$ (CH$_2$OH), 57.8$^+$ (O*C*HCH$_2$OH), 55.5$^+$ ($^2J_{PC}$ 4.4, PCH*C*HO), 43.8$^+$ ($^1J_{PC}$ 66.0, PCH), 21.4$^-$ ($^2J_{PC}$ 1.4, PCH*C*H$_2$) and 12.9$^+$ (Me); *m/z* 316 (0.8%, M$^+$), 298 (0.7, M − H_2O), 285 (2.3, M − CH_2OH), 219 (8, $Ph_2PO_2H_2$), 202 (57, Ph_2POH), 201 (48, Ph_2PO) and 58 (100). Integration of the ^1H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of 82%.

Also eluted from the HPLC machine was material (299.5 mg) the ^1H NMR of which showed it to consist of 75% starting material **5i** and 25% of the *syn* epoxide *syn*-**6i**. Integration of the ^1H NMR spectrum of the Mosher ester of this material indicated that the remaining starting material **5i** had an enantiomeric excess of 31%.

Kinetic Resolution of **5j**.—By Method D, the allylic alcohol[6] **5j** (514.4 mg, 1.50 mmol) gave, after 6 days at −17 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–5% MeOH, gave a mixture of compounds which was shown, by integration of the preparative HPLC trace, to consist of 48% starting material plus a 68:32 mixture of the epoxides *anti*-**6j** and *syn*-**6j**. Further purification by HPLC, eluting with $CHCl_3$–3% MeOH, gave (2*S*,3*R*,4*S*)-4-diphenylphosphinoyl-2,3-epoxynonan-1-ol *anti*-**6j** (140 mg, 26%) as an oil, $[\alpha]_D^{25}$ −34.6 (*c* 1.18 in $CHCl_3$), retention time 13 min (Found: M$^+$, 358.1669. $C_{21}H_{27}O_3P$ requires *M*, 358.1698); R_F(EtOAc) 0.19; ν_{max}($CHBr_3$)/cm^{-1} 3380 (OH), 1435 (PPh) and 1150 (P=O); δ_H(250 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.6 (1 H, br s, OH), 3.40 (1 H, dd, *J* 13 and 3, C*H*$_A$H$_B$OH), 3.23 (1 H, dd, *J* 13 and 4.5, CH$_A$*H*$_B$OH), 3.20 (1 H, d × fine m, *J* 8, PCHC*H*O), 2.39 (1 H, fine m, OC*H*CH$_2$OH), 2.12 (1 H, dq, *J* 4 and 9, PCH), 2.0–1.1 [8 H, m, (CH$_2$)$_4$] and 0.83 (3 H, t, *J* 7, Me); δ_C(100 MHz; $CDCl_3$) 133–128 (Ph_2PO), 61.3$^-$ (CH$_2$OH), 57.9$^+$ (O*C*HCH$_2$OH), 55.6$^+$ ($^2J_{PC}$ 4.4, PCH*C*HO), 42.6$^+$ ($^1J_{PC}$ 65.5, PCH), 31.7$^-$ (PCH*C*H$_2$), 27.9$^-$, 27,8$^-$, 27.7$^-$ [(*C*H$_2$)$_3$Me] and 14.0$^+$ (Me); *m/z* 358 (0.5%, M$^+$), 327 (20, M − CH_2OH), 283 (24), 257 (22, M − CH_2OH − C_5H_{10}), 219 (5, $Ph_2PO_2H_2$), 202 (98, Ph_2POH) and 201 (100, Ph_2PO).

Also eluted from the HPLC machine was (2*S*,3*R*,4*R*)-4-diphenylphosphinoyl-2,3-epoxynonan-1-ol *syn*-**6j** (60 mg, 11%) as an oil, $[\alpha]_D^{25}$ −7.3 (*c* 2.16 in $CHCl_3$), retention time 15 min (Found: M$^+$, 358.1699. $C_{21}H_{27}O_3P$ requires *M*, 358.1698); R_F (EtOAc) 0.13; ν_{max}($CHBr_3$)/cm^{-1} 3370 (OH), 1435 (PPh) and 1150 (P=O); δ_H(250 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.76 (1 H, dd, *J* 12.5 and 3.6, C*H*$_A$H$_B$OH), 3.59 (1 H, dd, *J* 12.5 and 4.5, CH$_A$*H*$_B$OH), 3.16 (1 H, ddd, *J* 8, 4.5 and 2, PCHC*H*O), 3.16 (1 H, fine m, OC*H*CH$_2$OH), 2.30 (1 H, qn, *J* 7, PCH), 1.7–1.1 [8 H, m, (CH$_2$)$_4$] and 0.81 (3 H, t, *J* 7, Me); δ_C(100 MHz; $CDCl_3$) 132–128 (Ph_2PO), 61.3$^-$ (CH$_2$OH), 57.9$^+$ ($^3J_{PC}$ 10.9, OCHCH$_2$OH), 53.7$^+$ ($^2J_{PC}$ 2.2, PCH*C*HO), 40.7$^+$ ($^1J_{PC}$ 68.5, PCH), 31.5$^-$ (PCH*C*H$_2$), 28.1$^-$ ($^3J_{PC}$ 10.9, PCHCH$_2$*C*H$_2$), 24.9$^-$ ($^4J_{PC}$ 2.2, *C*H$_2$CH$_2$Me), 22.3$^-$ (*C*H$_2$Me) and 13.9$^+$ (Me); *m/z* 358 (1%, M$^+$), 327 (12, M − CH_2OH), 257 (62, M − CH_2OH − C_5H_{10}), 219 (22, $Ph_2PO_2H_2$), 202 (100, Ph_2POH) and 201 (100, Ph_2PO).

Also eluted from the HPLC machine was the allylic alcohol **5j** (140 mg, 27%), $[\alpha]_D^{25}$ +9.2 (*c* 0.48 in $CHCl_3$), retention time 16 min. Integration of the ^1H NMR spectrum of the Mosher's ester of this material indicated an enantiomeric excess of 36%.

Kinetic Resolution of **5k**.—By Method D, the allylic alcohol[6] **5k** (619.3 mg, 2.0 mmol) gave, after 7 days, a crude product. Integration of the ^1H NMR spectrum of this material showed it to consist of a 53:47 mixture of starting material and epoxide products. Purification by flash chromatography, eluting with EtOAc–4% MeOH, followed by HPLC, eluting with EtOAc–4% MeOH, gave a 93:7 mixture of the epoxide *anti*-**6k** and the epoxide[2] *syn*-**6k** (220.4 mg, 33%) from which it was possible to isolate a pure sample of (2*S*,3*R*,4*S*)-4-diphenylphosphinoyl-2,3-epoxy-5-methylhexan-1-ol *anti*-**6k** as prisms, m.p. 175–176.5 °C (from EtOAc), $[\alpha]_D^{25}$ +34.1 (*c* 1.93 in $CHCl_3$), retention time 27 min (Found: C, 69.0; H, 6.95; P, 9.4%; M$^+$, 330.1360. $C_{19}H_{23}O_3P$ requires C, 69.08; H, 7.02; P, 9.38%; *M*, 330.1385); R_F(EtOAc) 0.33; ν_{max}($CHCl_3$)/cm^{-1} 3360 (OH), 1435 (PPh) and 1150 (P=O); δ_H(250 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.34 (1 H, dt, *J* 9.5 and 1.9, PCHC*H*O), 3.30 (1 H, dd, *J* 12.4 and 2.1, C*H*$_A$H$_B$OH), 3.12 (1 H, dd, *J* 12.6 and 4.5, CH$_A$*H*$_B$OH), 2.30 (1 H, d × septet, *J* 2.7 and 7.0, C*H*Me$_2$), 2.25 (1 H, fine m,

OC*H*CH_2OH), 2.01 (1 H, dt, *J* 2.6 and 9.4, PCH), 1.21 (3 H, d, *J* 6.8, CH$Me_A$$Me_B$) and 1.09 (3 H, d, *J* 6.8, CH$Me_A$$Me_B$); δ_C (100 MHz; $CDCl_3$) 134–128 (Ph_2PO), 61.3$^-$ (CH_2OH), 57.9$^+$ (O*C*HCH$_2$OH), 52.3$^+$ ($^2J_{PC}$ 5.1, PCH*C*HO), 47.2$^+$ ($^1J_{PC}$ 65.2, PCH), 27.9$^+$ (*C*HMe$_2$), 23.9$^+$ ($^3J_{PC}$ 12.8, CH$Me_A$$Me_B$) and 17.0$^+$ (CH$Me_A$$Me_B$); *m/z* 330 (1%, M$^+$), 299 (1.5, M – CH_2OH), 257 (29, M – CH_2OH – C_3H_6), 219 (8, $Ph_2PO_2H_2$) and 201 (100, Ph_2PO). Integration of the ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of 86%.

Also eluted from the HPLC machine was allylic alcohol **5k** (241.2 mg, 39%), $[\alpha]_D^{25}$ +28.8 (*c* 1.35 in $CHCl_3$), retention time 35 min. Integration of the ^{1}H NMR spectrum of the Mosher's ester of this material indicated an enantiomeric excess of 65%.

Crystallisation of the mixture of starting material and epoxide products from a variety of solvents gave material containing a 1:1 mixture of starting material and product. Repeated crystallisation of the 93:7 mixture of epoxides **6k** from ethyl acetate did not alter the product ratio, but returned crystals of only 16% ee (by integration of the ^{1}H NMR spectrum in the presence of Pirkle's chiral shift reagent). These crystals were used to determine the crystal structure of the *anti* epoxide *anti*-**6k**.

Kinetic Resolution of **5l**.—By Method D, the allylic alcohol[6] **5l** (712.9 mg, 2.01 mmol) gave, after 5 days at −15 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–2% MeOH, gave a mixture of compounds (660 mg) of which integration of the ^{1}H NMR spectrum showed to consist of a 56:44 mixture of starting material and epoxide products. Further purification by HPLC, eluting with $CHCl_3$–3% MeOH, gave (2*S*,3*R*,4*S*)-4-cyclohexyl-4-diphenylphosphinoyl-2,3-epoxybutan-1-ol *anti*-**6l** (184.3 mg, 24%) as a foam, $[\alpha]_D^{25}$ −31.6 (*c* 0.89 in $CHCl_3$), retention time 12 min (Found: M – OCHCHCH$_2$OH, 296.1313. $C_{22}H_{27}O_3P$ requires *M* – OCHCHCH$_2$OH, 296.1330); R_F(EtOAc) 0.19; ν_{max}(Nujol)/cm^{-1} 3290 (OH), 1440 (PPh) and 1180 (P=O); δ_H(250 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.6 (1 H, br s, OH), 3.39 (1 H, d × fine m, *J* 9.5, PCHC*H*O), 3.32 (1 H, dd, *J* 13 and 2, C$H_A$$H_B$OH), 3.15 (1 H, dd, *J* 13 and 4.5, CH$_A$$H_B$OH), 2.29 (1 H, fine m, OC*H*CH$_2$OH) and 2.2–1.0 (12 H, m, ring and PCH); δ_C(100 MHz; $CDCl_3$) 134–128 (Ph_2PO), 61.4$^-$ (CH_2OH), 58.3$^+$ (O*C*HCH$_2$OH), 52.2$^+$ ($^2J_{PC}$ 4.9, PCH*C*HO), 47.4$^+$ ($^1J_{PC}$ 64.9, PCH), 38.0$^+$ ($^2J_{PC}$ 1.5, PCH*C*HCH$_2$), 34.2$^-$ [$^3J_{PC}$ 11.6, PCHCH(*C*H$_2$)$_A$(CH$_2$)$_B$], 29.7$^-$ [$^3J_{PC}$ 2.2, PCHCH-(CH$_2$)$_A$(*C*H$_2$)$_B$], 27.0$^-$, 26.5$^-$ and 24.9$^-$ [(CH$_2$)$_3$]; *m/z* 296 (4%, M – CH(O)CHCH$_2$OH), 219 (24, $Ph_2PO_2H_2$), 202 (19, Ph_2POH), 201 (37, Ph_2PO) and 75 (100). Integration of the ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of 75%.

Also eluted from the HPLC machine was material (338.0 mg) which ^{1}H NMR showed to consist of a 93:7 ratio of remaining starting material **5l** and *syn* epoxide *syn*-**6l**: in other words, overall a 44% yield of recovered starting material **5l** and a 90:10 ratio of *anti*:*syn* epoxides *anti*-**6l** and *syn*-**6l**. Integration of the ^{1}H NMR spectrum of the Mosher's ester of this material showed that the remaining starting material **5l** had an enantiomeric excess of 63%.

From another experiment, some of the epoxide[2] *syn*-**6l** was isolated, $[\alpha]_D^{25}$ −6.6 (*c* 2.01 in $CHCl_3$).

Asymmetric Epoxidation of **5i**.—By Method B, the allylic alcohol[6] **5i** (303.6 mg, 1.01 mmol) with titanium tetraisopropoxide (0.20 cm^3, 0.66 mmol, 0.66 equiv.), L-(+)-diisopropyl tartrate (198.4 mg, 0.85 mmol, 0.85 equiv.) and *tert*-butyl hydroperoxide (3 mol dm^{-3} solution in 2,2,4-trimethylpentane; 0.66 cm^3, 2.0 mmol, 2.0 equiv.) gave, after 2.5 days at −20 °C followed by 12 h at +4 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–7% MeOH, gave a 50:50 (by HPLC) mixture of *syn* and anti epoxides *syn*-**6i** and *anti*-**6i** (210 mg, 66%), which were separated by HPLC, eluting with $CHCl_3$–4% MeOH, to give *anti*-**6i** (122.9 mg, 38%), retention time 11.5 min. Integration of the ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of 90%.

Also eluted from the HPLC machine was (2*S*,3*R*,4*R*)-4-diphenylphosphinoyl-2,3-epoxyhexan-1-ol *syn*-**6i** as an oil, $[\alpha]_D^{25}$ +3 (*c* 0.26 in $CHCl_3$) (Found: M$^+$, 316.1205. $C_{18}H_{21}O_3P$ requires *M*, 316.1229); R_F(EtOAc–2.5% MeOH) 0.12; ν_{max}($CHCl_3$)/cm^{-1} 3350 (OH), 1440 (PPh) and 1130 (P=O); δ_H(250 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.75 (1 H, dd, *J* 12 and 3.5, C$H_A$$H_B$OH), 3.61 (1 H, dd, *J* 12 and 4, CH$_A$$H_B$OH), 3.4 (1 H, br s, OH), 3.16 (1 H, ddd, *J* 8, 5 and 2, PCHC*H*O), 3.06 (1 H, fine m, OC*H*CH$_2$OH), 2.2 (1 H, m, PCH), 1.7 (2 H, m, PCHCH_2) and 1.00 (3 H, t, *J* 7, Me); δ_C(100 MHz; $CDCl_3$) 133–128 (Ph_2PO), 61.4$^-$ (CH_2OH), 57.9$^+$ ($^3J_{PC}$ 11.0, O*C*HCH$_2$OH), 53.6$^+$ ($^2J_{PC}$ 2.2, PCH*C*HO), 42.3$^+$ ($^1J_{PC}$ 68.5, PCH), 18.6$^-$ ($^2J_{PC}$ 2.1, PCH*C*H$_2$) and 13.2$^+$ ($^3J_{PC}$ 11.7, Me); *m/z* 316 (3%, M$^+$), 298 (0.8, M – H_2O), 285 (6, M – CH_2OH), 257 (18, M – CH_2OH – C_2H_4), 219 (18, $Ph_2PO_2H_2$), 202 (80, Ph_2POH) and 201 (100, Ph_2PO).

Integration of the ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated an enantiomeric excess of >95%.

Asymmetric Epoxidation of **5k**.—By Method B, the allylic alcohol[6] **5k** (304.8 mg, 0.97 mmol) with titanium tetraisopropoxide (0.20 cm^3, 0.66 mmol, 0.66 equiv.), L-(+)-diisopropyl tartrate (203.5 mg, 0.87 mmol, 0.90 equiv.) and *tert*-butyl hydroperoxide (3 mol dm^{-3} solution in 2,2,4-trimethylpentane; 0.66 cm^3, 2.0 mmol, 2.0 equiv.) gave, after 2.5 days at −20 °C followed by 2.5 days at +4 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–cyclohexane (5:1), then EtOAc, and then EtOAc–5% MeOH, gave the aldehyde **11** (66.1 mg, 21%) as prisms, m.p. 121–122 °C (from EtOAc), $[\alpha]_D^{25}$ +0.73 (*c* 0.68 in $CHCl_3$) (Found: M$^+$, 312.1297. $C_{19}H_{21}O_2P$ requires *M*, 312.1279); R_F(EtOAc) 0.46; ν_{max}(Nujol)/cm^{-1} 1683 (C=O), 1462 (PPh) and 1190 (PO); δ_H(250 MHz; $CDCl_3$) 9.47 (1 H, d, *J* 7.8, CHO), 7.9–7.4 (10 H, m, Ph_2PO), 7.00 (1 H, ddd, *J* 16.0, 11.0 and 6.5, PCHC*H*=CH), 5.94 (1 H, ddd, *J* 16.0, 8.0 and 4.0, C*H*CHO), 3.18 (1 H, ddd, *J* 11.0, 8.0 and 3.5, PCH), 2.33 (1 H, m, C*H*Me$_2$), 1.17 (3 H, d, *J* 7.0, CH$Me_A$$Me_B$) and 0.93 (3 H, d, *J* 7.0, CHMe$_A$$Me_B$); *m/z* 312 (25%, M$^+$), 219 (20, $Ph_2PO_2H_2$), 202 (60, Ph_2POH) and 201 (100, Ph_2PO).

Also obtained was a 71:17:11 mixture of *anti*-**6k**, starting material **5k** and *syn*-**6k** (201.4 mg). Attempted purification of this material by crystallisation from ethyl acetate returned a 73:21:5 mixture of the same three compounds.

Optimisation of the Kinetic Resolution of **5k**.—By Method B, the allylic alcohol[6] **5k** (620 mg, 2.0 mmol), with titanium tetraisopropoxide (0.30 cm^3, 1.0 mmol, 0.5 equiv.), L-(+)-diisopropyl tartrate (290 mg, 1.25 mmol, 0.6 equiv.) or L-(+)-dicyclohexyl tartrate (prepared according to the method of Sharpless[4c]) (390 mg, 1.25 mmol, 0.6 equiv.) and *tert*-butyl hydroperoxide (3 mol dm^{-3} solution in 2,2,4-trimethylpentane; 0.33 cm^3 1.0 mmol, 0.5 equiv.) or triphenymethyl hydroperoxide (277 mg, 1.0 mmol, 0.5 equiv.) gave, after 7 days at −16 °C or +4 °C, a crude product. This was purified by flash chromatography, eluting with EtOAc–2.5% MeOH, to give a mixture of compounds. Percentage completion and diastereoisomeric ratios were determined from the ^{1}H NMR spectrum of this material. Further purification by HPLC, eluting with $CHCl_3$–4% MeOH, gave a pure sample of the *anti* epoxide *anti*-**6k**. The enantiomeric excess of this material was determined by integration of the ^{1}H NMR spectrum of this material in the

presence of Pirkle's chiral shift reagent. The results obtained from these experiments are recorded in Table 5.

Attempted Kinetic Resolution of anti-**13a**.—By Method D, the diol[19] *anti*-**13a** (186.4 mg, 0.564 mmol) gave, after 5 days at −18 °C, and after purification by flash chromatography, eluting with EtOAc–5% MeOH, only starting material (173.9 mg, 93%).

Attempted Kinetic Resolution of syn-**13a**.—By Method D, the diol[19] *syn*-**13a** (90.0 mg, 0.272 mmol) gave, after 5 days at −18 °C, and after purification by flash chromatography, eluting with EtOAc–5% MeOH, only starting material (76.8 mg, 85%).

Kinetic Resolution of anti-**13b**.—By Method D, the allylic alcohol[19] *anti*-**13b** (831 mg, 2.231 mmol) gave, after 5 days at −16 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–5% MeOH, gave a mixture of compounds (756 mg) which was shown by ^{1}H NMR to consist of 55% remaining starting material *anti*-**13b** and 45% of a 86:14 mixture of the epoxides *anti,anti*-**14b** and *anti,syn*-**14b**. Further purification by HPLC, eluting with CH_2Cl_2–6% MeOH, gave the *anti,anti* epoxide (2*S*,3*R*,4*S*,5*R*)-5-acetoxy-4-diphenylphosphinoyl-2,3-epoxyheptan-1-ol *anti,anti*-**14b** (180.3 mg, 21%) as a powder, m.p. 160–162 °C (from EtOAc–MeOH), $[\alpha]_D^{25}$ −41.8 (*c* 0.56 in $CHCl_3$), retention time 18 min (Found: C, 65.0; H, 6.55; P, 8.0%. $C_{21}H_{25}O_5P$ requires C, 64.94; H, 6.49; P, 7.97%); R_F(EtOAc) 0.10; ν_{max}($CDCl_3$)/cm^{-1} 3310 (OH), 1730 (C=O), 1440 (PPh) and 1180 (P=O); δ_H(400 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 5.25 (1 H, m, C*H*OAc), 3.46 (1 H, d × fine m, *J* 9.2, PCHC*H*O), 3.37 (1 H, dd, *J* 12.6 and 2.7, C*H*$_A$H$_B$OH), 3.21 (1 H, dd, *J* 12.6 and 3.9, CH$_A$*H*$_B$OH), 2.45–2.4 (2 H, m, PCH and HOCH$_2$C*H*O), 2.1 (1 H, br s, OH), 2.0–1.7 (2 H, m, C*H*$_2$Me), 1.78 (3 H, s, Ac) and 0.86 (3 H, t, *J* 7.4, CH$_2$*Me*); δ_C(100 MHz; $CDCl_3$) 170.0$^-$ (C=O), 133–128 (Ph_2PO), 72.6$^+$ (*C*HOAc), 61.2$^-$ (CH_2OH), 57.8$^+$ (O*C*HCH$_2$OH), 51.9$^+$ ($^2J_{PC}$ 5.3, PCH*C*HO), 45.3$^+$ ($^1J_{PC}$ 65.0, PCH), 26.3 ($^3J_{PC}$ 8.4, *C*H$_2$Me), 20.8$^+$ (*Me*CO) and 10.2$^+$ (CH$_2$*Me*); *m*/*z* 257 (5%, $Ph_2POC_3H_4O$), 219 (11, $Ph_2PO_2H_2$), 202 (24, Ph_2POH), 201 (28, Ph_2PO) and 69 (100). The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 87%.

Also obtained was remaining starting material *anti*-**13b** (332.9 mg, 40%), $[\alpha]_D^{25}$ +21.3 (*c* 1.18 in $CHCl_3$), retention time 22 min. The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 26%.

Further fractions from the HPLC column contained a mixture of *anti-anti*-**14b** and *anti,syn*-**14b** (57.0 mg, 6.6%).

Kinetic Resolution of syn-**13b**.—By Method D, the allylic alcohol[19] *syn*-**13b** (318 mg, 0.854 mmol) gave, after 5 days at −18 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–5% MeOH, gave a mixture of compounds (330 mg) which was shown by ^{1}H NMR to consist of 55% remaining starting material **13b** and 45% of a 75:25 mixture of epoxides *syn,anti*-**14b** and *syn,syn*-**14b**. Further purification by HPLC, eluting with CH_2Cl_2–6% MeOH, allowed isolation of a mixture of the two epoxides *syn,anti*- and *syn,syn*-**14b**, retention time 20 min. Partial separation of these two products was achieved by HPLC, eluting with EtOAc–5% MeOH, to yield the *syn,anti* epoxide (2*S*,3*R*,4*R*,5*S*)-5-acetoxy-4-diphenylphosphinoyl-2,3-epoxyheptan-1-ol *syn,anti*-**14b** (35.6 mg, 10.5%) as an oil, $[\alpha]_D^{25}$ −7.0 (*c* 2.45 in $CDCl_3$). (Found: M − OAc, 330.1390. $C_{21}H_{25}O_5P$ requires *M* − OAc, 330.1389); R_F(EtOAc) 0.20; ν_{max}($CDCl_3$)/cm^{-1} 3310 (OH), 1730 (C=O), 1440 (PPh) and 1180 (P=O); δ_H(400 MHz; $CDCl_3$) 8.0–7.4 (10 H, m, Ph_2PO), 4.99 (1 H, m, C*H*OAc), 3.39 (1 H, d × fine m, *J* 8.8, PCHC*H*O), 3.36 (1 H, dd, *J* 12.7 and 2.7, C*H*$_A$H$_B$OH), 3.19 (1 H, dd, *J* 12.8 and 3.9, CH$_A$*H*$_B$OH), 2.77 (1 H, dt, 4.8 and 10.1, PCH), 2.3 (1 H, br s, OH), 2.17 (1 H, fine m, HOCH$_2$C*H*O), 2.2–1.8 (2 H, m, C*H*$_2$Me), 1.90 (3 H, s, Ac) and 0.81 (3 H, t, *J* 7.3, CH$_2$*Me*); δ_C(100 MHz; $CDCl_3$) 171.2$^-$ (C=O), 133–128 (Ph_2PO), 74.7$^+$ ($^2J_{PC}$ 3.2, *C*HOAc), 61.0$^-$ (CH_2OH), 57.3$^+$ (O*C*HCH$_2$OH), 51.3$^+$ ($^2J_{PC}$ 2.6, PCH*C*HO), 44.6$^+$ ($^1J_{PC}$ 63.2, PCH), 24.2$^-$ (*C*H$_2$Me), 20.9$^+$ (*Me*CO) and 10.3$^+$ (CH$_2$*Me*); *m*/*z* 329 (10%, M − AcOH), 219 (70, $Ph_2PO_2H_2$), 202 (100, Ph_2POH) and 201 (98, Ph_2PO). The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 86%.

Also obtained was a 76:24 (by ^{1}H NMR) mixture of the two epoxides *syn,anti*- and *syn,syn*-**14b** (52.0 mg, 15.7%).

Also obtained from the first HPLC separation was remaining starting material *syn*-**13b** (126.4 mg, 32%), $[\alpha]_D^{25}$ +2.5 (*c* 0.89 in $CHCl_3$), retention time 24 min. The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 42%.

Kinetic Resolution of anti-**13c**.—By Method D, the allylic alcohol[6] *anti*-**13c** (454.0 mg, 1.38 mmol) gave, after 5 days at −18 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–5% MeOH, gave a mixture of compounds (433 mg) which was shown by analytical HPLC, eluting with $CHCl_3$–2.5% MeOH, to consist of 53% unchanged starting material *anti*-**13c** and 47% of a 91:9 mixture of epoxides *anti,anti*-**14c** and *anti,syn*-**14c**. Further purification by HPLC, eluting with $CHCl_3$–2.5% MeOH, have the *anti,anti* epoxide (2*S*,3*R*,4*S*,5*S*)-4-diphenylphosphinoyl-2,3-epoxy-5-methylheptan-1-ol *anti,anti*-**14c** (182.1 mg, 38%) as prisms, m.p. 148–150 °C (from EtOAc), $[\alpha]_D^{25}$ −39.2 (*c* 1.34 in $CDCl_3$), retention time 18 min (Found: C, 69.6; H, 7.3; P, 9.0%; M + H, 345.1594. $C_{20}H_{25}O_3P$ requires C, 69.75; H, 7.32; P, 8.99%; *M* + H, 345.1619); R_F(EtOAc) 0.20; ν_{max}($CDCl_3$)/cm^{-1} 3310 (OH), 1440 (PPh) and 1180 (P=O); δ_H(400 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.34 (1 H, dt, *J* 9.6 and 2.0, PCHC*H*O), 3.31 (1 H, dd, *J* 12.1 and 2.1, C*H*$_A$H$_B$OH), 3.15 (1 H, dd, *J* 12.1 and 2.1, CH$_A$*H*$_B$OH), 2.31 (1 H, qn, *J* 2.1, OC*H*CH$_2$O), 2.07 (1 H, dt, 2.5 and 9.6, PCH), 2.06 (1 H, m, C*H*Me), 2.0 (1 H, br s, OH), 1.96 (2 H, m, C*H*$_A$H$_B$Me), 1.38 (1 H, dqn, *J* 16.5 and 7.2, CH$_A$*H*$_B$Me), 1.10 (3 H, d, *J* 6.8, CH*Me*) and 0.80 (3 H, t, *J* 7.3, CH$_2$*Me*); δ_C(62.9 MHz; $CDCl_3$) 133–128 (Ph_2PO), 61.2$^-$ (CH_2OH), 58.0$^+$ (O*C*HCH$_2$OH), 52.9$^+$ ($^2J_{PC}$ 5.1, PCH*C*HO), 47.7$^+$ ($^1J_{PC}$ 65.2, PCH), 36.0$^+$ (*C*HMe), 25.7$^-$ (*C*H$_2$Me), 19.6$^+$ ($^3J_{PC}$ 12.8, CH*Me*) and 12.3$^+$ (CH$_2$*Me*); *m*/*z* (+FAB) 345 (100%, M + H), 219 (48, $Ph_2PO_2H_2$), 202 (12, Ph_2POH and 201 (48, Ph_2PO). The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 70%.

Also obtained was the *anti,syn* epoxide (2*S*,3*R*,4*R*,5*R*)-4-diphenylphosphinoyl-2,3-epoxy-5-methylheptan-1-ol *anti,syn*-**14c** (14.6 mg, 3%) as an oil, $[\alpha]_D^{25}$ −0.2 (*c* 1.47 in $CDCl_3$), retention time 20.5 min (Found: M + H, 345.1647. $C_{20}H_{26}O_3P$ requires *M*, 345.1619); R_F(EtOAc) 0.20; ν_{max}($CDCl_3$)/cm^{-1} 3310 (OH), 1440 (PPh) and 1180 (P=O); δ_H(400 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.81 (1 H, dd, *J* 12.6 and 2.2, C*H*$_A$H$_B$OH), 3.59 (1 H, dd, *J* 12.6 and 4.2, CH$_A$*H*$_B$OH), 3.30 (1 H, ddd, *J* 9.3, 5.4 and 2.2, PCHC*H*O), 3.06 (1 H, fine m, OC*H*CH$_2$O), 2.4 (1 H, br s, OH), 2.09 (1 H, ddd, 9.9, 7.6 and 2.7, PCH), 2.00 (2 H, m, C*H*Me and C*H*$_A$H$_B$Me), 1.15 (1 H, m, CH$_A$*H*$_B$Me), 1.02 (3 H, d, *J* 6.9, CH*Me*) and 0.77 (3 H, t, *J* 7.2, CH$_2$*Me*); δ_C(62.9 MHz; $CDCl_3$) 133–128 (Ph_2PO), 61.3$^-$ (CH_2OH), 59.1$^+$ ($^3J_{PC}$ 13.0, OCHCH$_2$OH), 52.1$^+$ ($^2J_{PC}$ 3.3, PCH*C*HO), 47.5$^+$ ($^1J_{PC}$ 68.1, PCH), 34.2$^+$ (*C*HMe), 26.0$^-$ (*C*H$_2$Me), 19.7$^+$ ($^3J_{PC}$ 12.3, CH*Me*) and 12.5$^+$ (CH$_2$*Me*); *m*/*z* (+FAB) 345 (95%, M + H), 219 (55, $Ph_2PO_2H_2$), 202 (25, Ph_2POH) and 201 (100, Ph_2PO).

Also obtained was remaining starting material *anti*-**13c** (184.3 mg, 41%), $[\alpha]_D^{25}$ +28.2 (*c* 1.14 in $CHCl_3$), retention time

21 min. The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 52%.

Kinetic Resolution of syn-**13c**.—By Method D, the allylic alcohol[6] *syn*-**13c** (391.5 mg, 1.9 mmol) gave, after 5 days at −18 °C, a crude product. Purification by flash chromatography, eluting with EtOAc–5% MeOH, gave a mixture of compounds (364 mg) which was shown by analytical HPLC, eluting with $CHCl_3$–2.5% MeOH, to consist of 46% unchanged starting material *syn*-**13c** and 54% of an 89:11 mixture of epoxides *syn,anti*-**14c** and *syn,syn*-**14c**. Further purification by HPLC, eluting with $CHCl_3$–2.5% MeOH, gave the *syn,anti* epoxide (2*S*,3*R*,4*S*,5*R*)-4-diphenylphosphinoyl-2,3-epoxy-5-methylheptan-1-ol *syn,anti*-**14c** (166.1 mg, 41%) as prisms, m.p. 160.5–163 °C (from EtOAc), $[\alpha]_D^{25}$ −21.8 (*c* 1.21 in $CDCl_3$), retention time 19 min (Found: C, 69.75; H, 7.4; P, 9.0%; M + H, 345.1653. $C_{20}H_{25}O_3P$ requires C, 69.75; H, 7.32; P, 8.99%; *M* + H, 345.1619); R_F(EtOAc) 0.20; $\nu_{max}(CDCl_3)/cm^{-1}$ 3350 (OH), 1440 (PPh) and 1150 (P=O); δ_H(400 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.37 (1 H, dt, *J* 9.6 and 2.1, PCHC*H*O), 3.33 (1 H, dd, *J* 12.5 and 2.9, CH_AH$_B$OH), 3.15 (1 H, dd, *J* 11.5 and 4.8, CH$_A$*H*$_B$OH), 2.31 (1 H, dq, *J* 4.8 and 2.3, OC*H*CH$_2$O), 2.16 (1 H, dt, 1.9 and 9.7, PCH), 1.97 (1 H, sextet, *J* 6.9, C*H*Me), 1.8 (1 H, br s, OH), 1.52 (2 H, m, C*H*$_2$Me), 1.24 (3 H, d, *J* 6.9, CH*Me*) and 0.84 (3 H, t, *J* 7.4, CH$_2$*Me*); δ_C(100 MHz; $CDCl_3$) 133–128 (Ph_2PO), 61.3$^-$ (CH_2OH), 57.7$^+$ (O*C*HCH$_2$OH), 52.1$^+$ ($^2J_{PC}$ 5.0, PCH*C*HO), 44.9$^+$ ($^1J_{PC}$ 65.4, PCH), 34.4$^+$ (*C*HMe), 30.2$^-$ (*C*H$_2$Me), 16.3$^+$ ($^3J_{PC}$ 12.8, CH*Me*) and 12.1$^+$ (CH$_2$*Me*); *m*/*z* (+FAB) 345 (100%, M + H), 219 (60, $Ph_2PO_2H_2$), 202 (30, Ph_2POH) and 201 (100, Ph_2PO). The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 72%.

Also obtained was the *syn,syn* epoxide (2*S*,3*R*,4*R*,5*S*)-4-diphenylphosphinoyl-2,3-epoxy-5-methylheptan-1-ol *syn,syn*-**14c** (17.1 mg, 4%) as an oil, $[\alpha]_D^{25}$ −15.1 (*c* 1.71 in $CDCl_3$), retention time 23.5 min (Found: M + H, 345.1634. $C_{20}H_{25}O_3P$ requires *M* + H, 345.1619); R_F(EtOAc) 0.20; $\nu_{max}(CDCl_3)/cm^{-1}$ 3310 (OH), 1440 (PPh) and 1180 (P=O); δ_H(400 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 3.84 (1 H, dd, *J* 12.5 and 1.7, CH_AH$_B$OH), 3.60 (1 H, dd, *J* 12.7 and 4.3, CH$_A$*H*$_B$OH), 3.33 (1 H, ddd, *J* 9.5, 5.7 and 2.3, PCHC*H*O), 3.02 (1 H, fine m, OC*H*CH$_2$O), 2.17 (1 H, ddd, *J* 9.7, 7.9 and 2.3, PCH), 1.97 (1 H, m, C*H*Me), 1.8 (1 H, br s, OH), 1.38 (2 H, qn, *J* 7.3, C*H*$_2$Me), 1.12 (3 H, d, *J* 7.1, CHMe) and 0.81 (3 H, t, *J* 7.3, CH$_2$*Me*); δ_C(62.9 MHz; $CDCl_3$) 133–128 (Ph_2PO), 61.5$^-$ (CH_2OH), 58.9$^+$ ($^3J_{PC}$ 13.4, O*C*HCH$_2$OH), 51.6$^+$ ($^2J_{PC}$ 5.6, PCH*C*HO), 44.7$^+$ ($^1J_{PC}$ 68.6, PCH), 33.8$^+$ (*C*HMe), 30.3$^-$ ($^3J_{PC}$ 12.3, *C*H$_2$Me), 16.3$^+$ (CH*Me*) and 12.1$^+$ (CH$_2$*Me*); *m*/*z* (+FAB) 345 (100%, M + H), 219 (60 $Ph_2PO_2H_2$), 202 (25, Ph_2POH) and 201 (80, Ph_2PO).

Also obtained was remaining starting material *syn*-**13c** (126.4 mg, 32%), $[\alpha]_D^{25}$ +15.5 (*c* 1.14 in $CHCl_3$), retention time 24 min. The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 80%.

Asymmetric Epoxidation of anti-**13b**.—By Method B, the allylic alcohol[19] *anti*-**13b** (1.571 g, 4.22 mmol), with *tert*-butyl hydroperoxide (2.8 mol dm^{-3} solution in 2,2,4-trimethylpentane; 3.5 cm^3, 9.8 mmol, 2.3 equiv.), gave, after purification by flash chromatography, eluting with EtOAc–5% MeOH, and then HPLC, eluting with $CHCl_3$–3% MeOH, *anti,anti*-**14b** (453.8 mg, 28%), retention time 47 min. The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of 83%.

Also obtained was (2*S*,3*R*,4*R*,5*S*)-5-acetoxy-4-diphenylphosphinoyl-2,3-epoxyheptan-1-ol *anti,syn*-**14b** (122.7 mg, 7.5%) as an oil, $[\alpha]_D^{25}$ +20.0 (*c* 0.50 in $CHCl_3$), retention time 51 min (Found: M − CH_2OH, 357.1278. $C_{21}H_{25}O_5P$ requires *M* − CH_2OH, 357.1255); R_F(EtOAc) 0.10; $\nu_{max}(CDCl_3)/cm^{-1}$ 3310 (OH), 1730 (C=O), 1440 (PPh) and 1180 (P=O); δ_H(400 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 5.33 (1 H, m, C*H*OAc), 3.81 (1 H, dd, *J* 12.6 and 1.7, CH_AH$_B$OH), 3.60 (1 H, dd, *J* 12.7 and 3.5, CH$_A$*H*$_B$OH), 3.29 (1 H, ddd, *J* 7.0, 4.8 and 2.2, PCHC*H*O), 3.10 (1 H, fine m, HOCH$_2$C*H*O), 2.49 (1 H, dt, *J* 3.8 and 9.1, CHP), 2.1 (1 H, br s, OH), 1.9–1.6 (2 H, m, C*H*$_2$Me), 1.76 (3 H, s, Ac) and 0.83 (3 H, t, *J* 7.4, CH$_2$*Me*); δ_C(100 MHz; $CDCl_3$) 170.0$^-$ (C=O), 133–128 (Ph_2PO), 72.8$^+$ (*C*HOAc), 61.2$^-$ (CH_2OH), 59.1$^+$ ($^3J_{PC}$ 11.3, O*C*HCH$_2$OH), 51.7$^+$ (PCH*C*HO), 44.9$^+$ ($^1J_{PC}$ 67.9, PCH), 26.4$^-$ ($^3J_{PC}$ 8.4, *C*H$_2$Me), 20.7$^+$ (*Me*CO) and 10.4$^+$ (CH$_2$*Me*); *m*/*z* 357 (45%, M − CH_2OH), 329 (42, M − AcO), 297 (65, M − CH_2OH − AcO), 269 (98), 357 (75, $Ph_2POC_3H_4O$), 219 (80, $Ph_2PO_2H_2$), 202 (98, Ph_2POH) and 201 (100, Ph_2PO).

Also obtained was remaining starting material *anti*-**13b** (173 mg, 11%), retention time 55 min. The ^{1}H NMR spectrum of this material in the presence of Pirkle's chiral shift reagent indicated that it had an enantiomeric excess of >90%.

Asymmetric Epoxidation of syn-**13b**.—By Method B, the allylic alcohol[19] *syn*-**13b** (286.7 mg, 0.770 mmol), with *tert*-butyl hydroperoxide (2.8 mol dm^{-3} solution in 2,2,4-timethylpentane; 0.3 cm^3, 0.84 mmol, 1.1 equiv.), gave, after purification by flash chromatography, eluting with EtOAc–5% MeOH, and then HPLC, eluting with $CHCl_3$–3% MeOH, *syn,anti*-**14b** (100.8 mg, 34%), retention time 34 min.

Also obtained was (2*S*,3*R*,4*R*,5*R*)-5-acetoxy-4-diphenylphosphinoyl-2,3-epoxyheptan-1-ol *syn,syn*-**14b** (45.0 mg, 15%) as an oil, $[\alpha]_D^{25}$ −93.8 (*c* 2.18 in $CDCl_3$), retention time 47 min (Found: M + H, 389.1543. $C_{21}H_{25}O_5P$ requires *M* + H, 385.1518); R_F(EtOAc) 0.10; $\nu_{max}(CDCl_3)/cm^{-1}$ 3310 (OH), 1720 (C=O), 1440 (PPh) and 1180 (P=O); δ_H(400 MHz; $CDCl_3$) 7.9–7.4 (10 H, m, Ph_2PO), 4.89 (1 H, m, C*H*OAc), 3.79 (1 H, dd, *J* 12.6 and 2.9, CH_AH$_B$OH), 3.60 (1 H, dd, *J* 12.7 and 4.3, CH$_A$*H*$_B$OH), 3.43 (1 H, ddd, *J* 8.6, 6.3 and 2.0, PCHC*H*O), 3.00 (1 H, fine m, HOCH$_2$C*H*O), 2.67 (1 H, dt, *J* 3.4 and 9.0, CHP), 2.6 (1 H, br s, OH), 2.14 (1 H, m, CH_AH$_B$Me), 1.93 (3 H, s, Ac), 1.74 (1 H, m, CH$_A$*H*$_B$Me) and 0.76 (3 H, t, *J* 7.2, CH$_2$*Me*); δ_C(100 MHz; $CDCl_3$) 170.7$^-$ (C=O), 133–128 (Ph_2PO), 74.5$^+$ ($^2J_{PC}$ 4.6, CHOAc), 61.4$^-$ (CH_2OH), 58.1$^+$ ($^3J_{PC}$ 10.9, OCHCH$_2$OH), 50.9$^+$ ($^2J_{PC}$ 3.2, PCH*C*HO), 45.2$^+$ ($^1J_{PC}$ 65.9, PCH), 24.7$^-$ (*C*H$_2$Me), 20.9$^+$ (*Me*CO) and 10.8$^+$ (CH$_2$*Me*); *m*/*z* (+FAB) 389 (90%, M + H), 219 (80, $Ph_2PO_2H_2$), 202 (30, Ph_2POH) and 201 (100, Ph_2PO).

Also obtained was remaining starting material *syn*-**13b** (59.5 mg, 21%).

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