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Asymmetric Induction Reactions. VII.[1] Palladium-Catalyzed Asymmetric α-Allylations of Carbonyl Compounds Using Chiral Sulfonamides as Chiral Ligands

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Palladium-catalyzed asymmetric α-allylations of carbonyl compounds were studied using various kinds of chiral sulfonamides derived from optically active α-amino acids as chiral ligands. Participation of the sulfonamide functionality in the palladium catalysis is discussed.

Key words asymmetric allylation; palladium catalyst; chiral sulfonamide; chiral ligand; catalytic asymmetric synthesis

Catalytic asymmetric synthesis[2] has received much attention in recent years for the preparation of optically active compounds, and many methodologies of asymmetric synthesis have been devised in order to improve enantio- and diastereoselectivity.[3] Among them, there is increasing interest in transition metal catalysts to establish highly efficient asymmetric synthetic methods,[4] since the reactions can proceed under much milder reaction conditions than those without catalysts, and great efforts have been made to develop efficient chiral ligands, such as phosphines, diamines, aminoalcohols, and diols.[5,6]

We have taken much interest in transition metal-[7] or Lewis acid-catalyzed asymmetric reactions using chiral organosulfur functionalities such as chiral sulfinyl[8,9] and sulfinate groups.[10] We describe here some transition metal-catalyzed asymmetric reactions of optically active sulfonamides.

Synthesis of Chiral Phosphine Ligands We have studied palladium-catalyzed asymmetric allylations using chiral phosphine ligands derived from easily obtainable optically active α-amino acids such as (*S*)-proline, (2*S*,4*S*)-hydroxyproline, (*S*)-alanine, (*S*)-valine, (*S*)-*tert*-leucine, and (*S*)-phenylalanine. The chiral phosphine ligands, (*S*)-*N*-acyl- and sulfonyl-2-(diphenylphosphinomethyl)pyrrolidines (**2a**—**g**), were prepared in the usual way, except for **2c**,[11] by the reaction of (*S*)-2-(diphenylphosphinomethyl)pyrrolidine (**1**),[11] readily derived from (*S*)-proline, with acetyl, benzoyl, methanesulfonyl, ethanesulfonyl, *p*-toluenesulfonyl, or (+)-camphor-10-sulfonyl chloride in the presence of triethylamine, respectively. The chiral diphosphine compounds, (2*S*,4*S*)-*N*-acyl- and sulfonyl-4-(diphenylphosphinyl)-2-(diphenylphosphinomethyl)pyrrolidine (**4a**,[12] **4b**,[13] **4c**,[14] **4d**, and **4e**), were prepared in the same way *via* (2*S*,4*S*)-4-(diphenylphosphinyl)-2-(diphenylphosphinomethyl)pyrrolidine (**3**),[15] starting from (2*S*,4*S*)-hydroxyproline.

The chiral phosphinyl sulfonamides **10a**—**f** were prepared starting from (*S*)-alanine (**5a**), (*S*)-valine (**5b**), (*S*)-*tert*-leucine (**5c**), and (*S*)-phenylalanine ethyl ester (**5d**), by the *N*-sulfonylation of **5a**—**d** with methane- or benzenesulfonyl chloride and the subsequent *N*-methylation of (*S*)-**6a**—**f** with methyl iodide, followed by the $LiAlH_4$ reduction of the esters in (*S*)-**7a**—**f**, the mesylation of the hydroxy groups in (*S*)-**8a**—**f** with methanesulfonyl chloride, and the phosphinylation of the mesylates (*S*)-**9a**—**f** with diphenylphosphinyl chloride-lithium metal, in fairly good yield in each step. The sulfonamides (*S*)-**13a**,**b**[16] were prepared *via* the same sequence, starting from (*S*)-**6b**,**c**.

Palladium-Catalyzed Asymmetric Allylations with Chiral Phosphine Ligands Initially, the palladium-catalyzed asymmetric allylations of methyl aminoacetate diphenyl ketimine (**14**)[17] using (*S*)-*N*-acyl-2-(diphenylphosphinomethyl)pyrrolidines (**2a**—**c**) as chiral ligands were studied. The reactions of the ester enolate of **14** (generated by treatment with lithium diisopropylamide (LDA)) with allyl acetate (1.5 eq) were carried out in tetrahydrofuran (THF) at −20——78 °C for 0.5—2 h in the presence of bis [(π–allyl)chloropalladium] ([PdCl(π–allyl)]$_2$) (0.03 eq) and **2a**—**c** (0.12 eq) to give the optically active α-allyl ester,

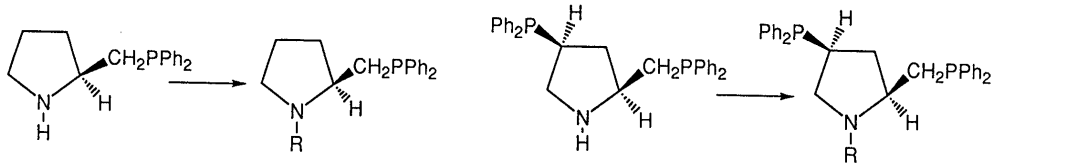

Chart 1

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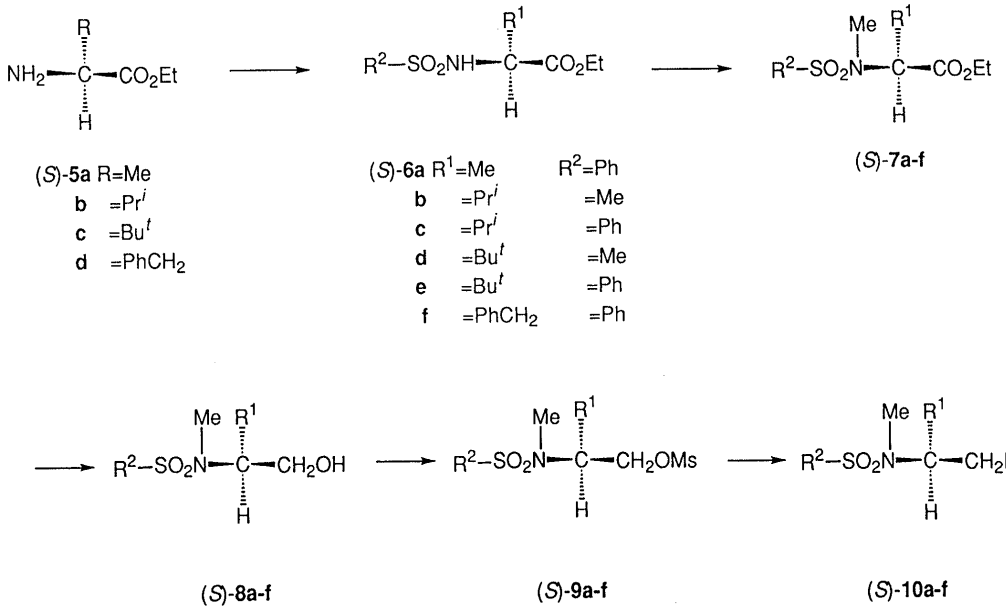
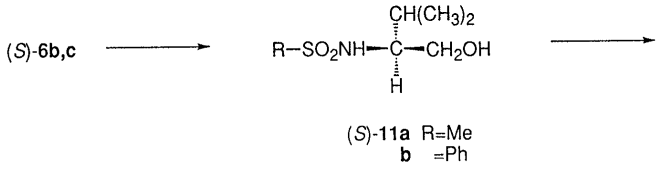


Chart 2



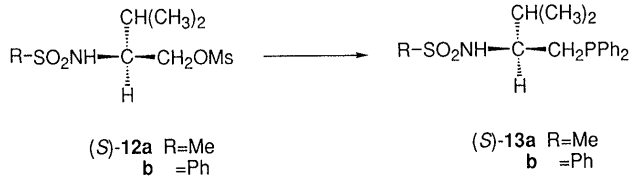


Chart 3

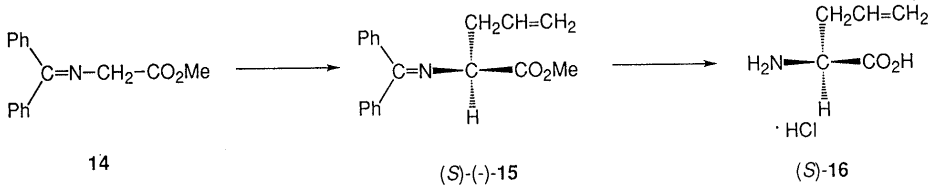


Chart 4

methyl (*R*)-2-amino-4-pentenoate diphenyl ketimine (**15**) with very low enantiomeric excess (e.e.).[18] The e.e. of the product **15** was determined on the basis of the optical rotation of **15** obtained (the optical rotation of optically pure (*R*)-(+)-**15**: $[\alpha]_D + 115°$ ($CHCl_3$)).[18] The absolute configuration of the newly created carbon center in the product **15** was determined previously by the conversion of **15** into methyl (*S*)-2-amino-4-pentenoate (**16**) of known absolute configuration.[19]

Slight (*S*)-selectivity for the product **15** was observed, except with (*S*)-**2b** in some cases. In contrast, the use of sulfonamide groups instead of the carboxamides in the chiral ligand **2** provided greater enantioselectivity for (*S*)-**15**. The asymmetric allylations of **14** with allyl acetate were carried out in a similar way in THF in the presence of **2d**—**g** (0.12 eq) and a palladium catalyst (0.03 eq) such as $[PdCl(\pi\text{-allyl})]_2$, palladium acetate $[Pd(OAc)_2]$, or bis(benzylideneacetone)palladium $[Pd(dba)_2]$. The yields and the e.e. of the product **15** obtained are summarized in Table 1. Surprisingly, as listed in Table 1, the degree of the asymmetric induction was not proportional to the steric bulk of the substituents of the sulfonyl groups in **2d**—**f**, and the bulkiest group (*p*-toluenesulfonyl in **2f**) was least effective for the asymmetric induction, giving (*S*)-**15** with the lowest e.e. It should be noted that the methanesulfonamide **2d** provided the highest e.e. of (*S*)-**15**, especially under the reaction conditions in THF at -20 or $-50\,°C$ using $[PdCl(\pi\text{-allyl})]_2$ (0.03 eq).

Table 1. Palladium-Catalyzed Asymmetric Allylations of Diphenyl Ketimine (**14**) with Chiral Ligands (*S*)-**2a**—**g**[a]

Ligand	Catalyst (eq)	Reaction temp. (°C)	Reaction time (h)	Yield of **15** (%)	$[\alpha]_D$ ($CHCl_3$) (*c*, °C)	e.e. of **15**[b] (%)
2a	A	−20	0.5	45	−1.2° (1.6, 26)	1 (*S*)
	A	−50	1	78	−8.3° (1.3, 25)	7 (*S*)
	A	−78	2	35	−16.5° (1.4, 26)	14 (*S*)
2b	A	−20	0.5	77	+3.8° (1.8, 26)	3 (*R*)
	A	−50	1	71	+2.8° (1.5, 26)	2 (*R*)
	A	−78	2	32	−0.6° (1.2, 27)	1 (*S*)
2c	A	−20	0.5	63	−16.3° (1.3, 24)	14 (*S*)
	A	−50	1	86	−17.3° (1.4, 25)	15 (*S*)
	A	−78	2	65	−13.9° (1.3, 26)	12 (*S*)
2d	A	0	0.25	82	−43.4° (1.7, 27)	38 (*S*)
	A	−20	0.5	100	−65.9° (1.5, 26)	57 (*S*)
	A	−50	1	82	−71.2° (1.4, 25)	62 (*S*)
	A	−78	2	25	−20.2° (1.3, 26)	17 (*S*)
	B	0	12	6	−26.9° (1.4, 27)	23 (*S*)
	B (0.06)	−20	3	38	−27.0° (1.2, 23)	23 (*S*)
	C (0.06)	−20	2	66	−40.6° (1.4, 24)	35 (*S*)
	C	−50	3	23	−42.1° (1.6, 26)	37 (*S*)
2e	A	−20	0.5	86	−31.0° (1.5, 24)	27 (*S*)
	A	−50	1	79	−34.9° (1.3, 23)	30 (*S*)
	A	−78	2	32	−32.1° (1.1, 24)	28 (*S*)
2f	A	r.t.	5	100	−2.4° (1.3, 24)	2 (*S*)
	A	−20	10	80	−4.6° (1.5, 26)	4 (*S*)
2g	A	0	0.25	81	−7.8° (1.3, 27)	7 (*S*)
	A	−20	0.5	100	−35.1° (1.5, 26)	30 (*S*)
	A	−50	1	92	−56.1° (1.5, 26)	49 (*S*)
	A	−78	2	36	−54.5° (1.4, 26)	47 (*S*)
	B	0	12	10	−20.9° (1.6, 27)	18 (*S*)
	B (0.06)	−20	3	48	−28.4° (2.1, 26)	25 (*S*)
	C	−50	3	49	−23.6° (1.7, 27)	21 (*S*)
	C (0.06)	−20	2	86	−22.3° (1.4, 25)	19 (*S*)

a) The reactions of **14** with allyl acetate were carried out in THF in the presence of a palladium catalyst [A: $[PdCl(\pi\text{-allyl})]_2$; B: $Pd(OAc)_2$; C: $Pd(dba)_2$] (0.03 eq if not described) and a chiral ligand (*S*)-**2a**—**g** (0.12 eq). *b*) The enantiomeric excess (e.e.) of **15** was determined on the basis of the optical rotation of **15** obtained (the optical rotation of optically pure (*R*)-(+)-**15**: $[\alpha]_D$ +115° ($CHCl_3$)).[18]

Table 2. Palladium-Catalyzed Asymmetric Allylations of Diphenyl Ketimine (**14**) with a Chiral Ligand (*S*)-**2d**[a]

Solvent	Reaction time (h)	Yield of **15** (%)	$[\alpha]_D$ ($CHCl_3$) (*c*, °C)	e.e. of (*S*)-**15**[b] (%)
THF	1	82	−71° (1.7, 26)	62
DME	2	53	−56° (1.5, 26)	48
Et_2O	1	74	−41° (1.2, 27)	35
Toluene	1	79	−10° (1.4, 26)	9
THF–dioxane (1 : 1)	2	76	−58° (1.1, 26)	50
THF–HMPA (1 : 1)	2	51	−61° (1.4, 25)	53

a) The reactions of **14** with allyl acetate were carried out in the presence of $[PdCl(\pi\text{-allyl})]_2$ (0.03 eq) and a chiral ligand **2d** (0.12 eq). *b*) The enantiomeric excess (e.e.) of **15** was determined on the basis of the optical rotation of **15** obtained (the optical rotation of optically pure (*R*)-(+)-**15**: $[\alpha]_D$ +115° ($CHCl_3$)).[18]

Introduction of a chiral group ((+)-camphorsulfonyl group) into the sulfonylamide (**2g**) resulted in much higher e.e. of the product (S)-15 than with **2e**, **f**, but less than with **2d**.

The palladium-catalyzed asymmetric allylations of **14** were studied at −50 °C by using the most effective chiral sulfonamide **2d** and the most efficient catalyst $[PdCl(\pi\text{-allyl})]_2$, among those examined. The results obtained are summarized in Table 2. Among the solvents employed, as listed in Table 2, THF exhibited the highest solvent effect on the asymmetric induction (62%), whereas toluene showed the lowest effect (9%), and the use of an additive (hexamethylphosphoramide (HMPA) or dioxane) in THF was not particularly effective.

Next, the bidentate phosphine ligands, (2*S*,4*S*)-**4a**—**e**, were examined in this palladium-catalyzed asymmetric allylation of **14**. The results are summarized in Table 3. The opposite stereoselectivity of the product was observed in this case. The allylations of **14** with allyl acetate were carried out in THF at −20——−78 °C in the presence of (2*S*,4*S*)-**4a**—**e** (0.12 eq) and $[PdCl(\pi\text{-allyl})]_2$ (0.03 eq) to afford (*R*)-(+)-**15**. In contrast to the results with **2a**—**g**, no marked effect of the sulfonamide group was observed in these palladium–bidentate phosphine ligand-catalyzed reactions, presumably because of the presence of the more reactive bidentate phosphine groups. Slightly greater e.e. of the product (*R*)-**15** was obtained with the carboxamides (2*S*,4*S*)-**4a**—**c** than with the sulfonamides (2*S*,4*S*)-**4d**, **e**.

Table 3. Palladium-Catalyzed Asymmetric Allylations of Diphenyl Ketimine (**14**) with Chiral Diphosphines (2*S*,4*S*)-**4a**—**e**[a]

Ligand	Reaction temp. (°C)	Reaction time (h)	Yield of **15** (%)	$[\alpha]_D$ ($CHCl_3$) of **15** (*c*, °C)	e.e. of (*R*)-**15**[b] (%)
4a	−20	0.5	84	+64.1° (1.8, 26)	56
	−50	1	56	+70.9° (1.6, 26)	62
	−78	2	24	+19.7° (1.2, 26)	17
4b	−20	0.5	41	+46.8° (1.5, 25)	41
	−50	1	27	+51.8° (1.8, 25)	45
	−78	2	26	+48.9° (1.4, 23)	42
4c	−20	0.5	70	+62.2° (1.5, 24)	54
	−50	1	72	+57.7° (1.4, 24)	51
	−78	2	19	+15.6° (1.5, 25)	14
4d	−20	0.5	84	+26.3° (1.7, 25)	23
	−50	1	80	+52.7° (1.6, 27)	46
	−78	2	24	+31.4° (1.9, 26)	27
4e	−20	0.5	83	+34.3° (1.5, 26)	30
	−50	1	79	+43.6° (1.6, 25)	38
	−78	2	20	+35.2° (1.2, 24)	31

a) The reactions of **14** with allyl acetate were carried out in THF in the presence of $[PdCl(\pi\text{-allyl})]_2$ (0.03 eq) and chiral ligands **4a**—**e** (0.12 eq). *b*) The enantiomeric excess (e.e.) of **15** was determined on the basis of the optical rotation of **15** obtained (the optical rotation of optically pure (*R*)-(+)-**15**: $[\alpha]_D$ +115° ($CHCl_3$)).[18]

Table 4. Palladium-Catalyzed Asymmetric Allylations of Diphenyl Ketimine (**14**) with Chiral Sulfonamides **10a**—**f** and (*S*)-**13a,b**[a]

Ligand	Reaction temp. (°C)	Reaction time (h)	Yield of **15** (%)	$[\alpha]_D$ ($CHCl_3$) (*c*, °C)	e.e. of **15**[b] (%)
10a	−20	0.5	85	+13.3° (1.2, 26)	12 (*R*)
	−50	1	62	+4.6° (1.5, 25)	4 (*R*)
	−78	2	18	+2.4° (1.2, 25)	2 (*R*)
10b	−20	0.5	66	+6.5° (1.3, 25)	6 (*R*)
	−50	1	25	+6.7° (1.5, 25)	6 (*R*)
	−78	2	10	+1.0° (1.6, 25)	1 (*R*)
10c	−20	0.5	45	−51.9° (1.6, 25)	45 (*S*)
	−50	1	57	−82.5° (1.9, 25)	72 (*S*)
	−78	2	4	−46.3° (1.5, 26)	40 (*S*)
10d	−20	0.5	94	−4.4° (1.5, 25)	4 (*S*)
	−50	1	83	−13.9° (1.7, 25)	12 (*S*)
	−78	2	30	−13.1° (1.7, 25)	11 (*S*)
10e	−20	0.5	28	+38.9° (1.6, 26)	34 (*R*)
	−50	1	71	+62.8° (1.6, 25)	55 (*R*)
	−78	2	27	+56.4° (1.6, 25)	49 (*R*)
10f	−20	0.5	56	−14.5° (1.4, 24)	13 (*S*)
	−50	1	29	−17.4° (1.6, 24)	15 (*S*)
	−78	2	11	−7.3° (1.7, 23)	6 (*S*)
(*S*)-**13a**	−50	1	30	+3.7° (1.7, 25)	3 (*R*)
(*S*)-**13b**	−50	1	16	−17.4° (1.3, 25)	15 (*S*)

a) The reactions of **14** with allyl acetate were carried out in THF in the presence of $[PdCl(\pi\text{-allyl})]_2$ (0.03 eq) and chiral ligands **10a**—**f** and (*S*)-**13a,b** (0.12 eq). *b*) The enantiomeric excess (e.e.) of **15** was determined on the basis of the optical rotation of **15** obtained (the optical rotation of optically pure (*R*)-(+)-**15**: $[\alpha]_D$ +115° ($CHCl_3$)).[18]

Finally, acyclic sulfonamides (*S*)-**10a**—**f** were used as chiral ligands in the palladium-catalyzed allylations of **14**. The asymmetric reactions of **14** with allyl acetate were carried out in THF at −20——78 °C in the presence of $[PdCl(\pi\text{-allyl})]_2$ (0.03 eq) and (*S*)-**10a**—**f** (0.12 eq), and the results are summarized in Table 4. When (*S*)-**10c** and (*S*)-**10e** were used as chiral ligands, rather high optical yields of the product **15** were obtained with opposite stereoselectivity ((*S*) and (*R*), respectively). The highest optical yield (72%) of (*S*)-**15** was observed with (*S*)-**10c** at −50 °C, and lower reaction temperature (−78 °C) decreased the optical (40%) and chemical yields of (*S*)-**15**.

It should be noted that the steric bulk of the sulfonyl groups played an important role in the enantioselectivity and the stereochemistry of the product **15**. The *N*-phenylsulfonyl substituent in the sulfonamide (*S*)-**10c**, **e** (R^2 = Ph) had a greater effect on the asymmetric induction than the *N*-methylsulfonyl group in (*S*)-**10b**, **d** (R^2 = Me), and the absolute configuration of the product with (*S*)-**10b**, **c** ($R^1 = Pr^i$) was opposite to that with (*S*)-**10d**, **e** ($R^1 = Bu^t$). The allylation of **14** with (*S*)-**10b** produced (*R*)-**15** with very low e.e., whereas the reaction with (*S*)-**10c** gave (*S*)-**15** with rather high e.e. Similar results were obtained in the reaction with (*S*)-**10d**, **e**, but the absolute configuration of the product **15** obtained with (*S*)-**10d**, **e** was opposite to that with (*S*)-**10b**, **c**.

The loss ((*S*)-**13a**, **b**) of the *N*-methyl group in the sulfonamides (*S*)-**10b**, **d** dramatically decreased the e.e. of the product **15**.

We applied this efficient method with the chiral sulfonamide (*S*)-**2d** to other nucleophilic substrates such as 2-(*p*-toluenesulfenyl)cyclohexanone (**17**), 2-acetylcyclo-

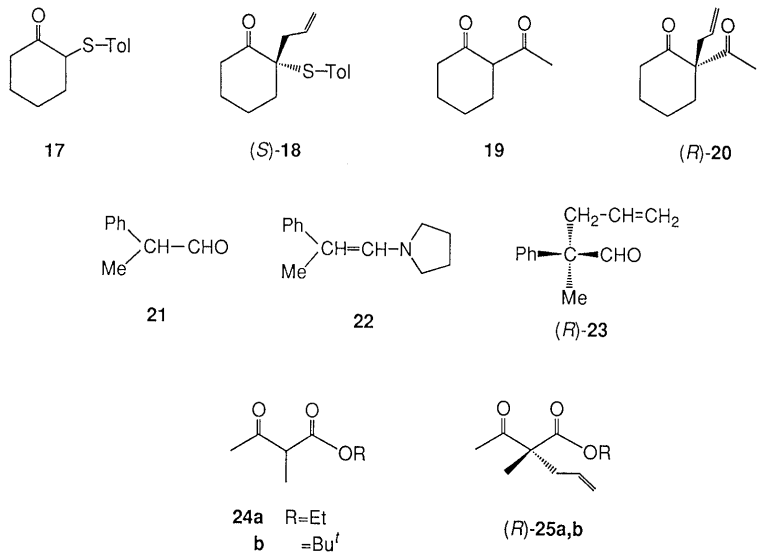


Chart 5

Table 5. Palladium-Catalyzed Asymmetric Allylations of Other Nucleophiles with a Chiral Ligand (*S*)-**2d**[a]

Nucleophile	Reaction temp. (°C)	Reaction time (h)	Product	Yield (%)	Product $[\alpha]_D$ (*c*, °C)	e.e. (%)[b]
17	0	3	(*S*)-**18**	35	−121° (1.1, 26)	48
19	−50	4	(*R*)-**20**	80	−80° (1.3, 25)	32
22	0	3	(*R*)-**23**	31	−14° (1.3, 26)	36
24a	−50	2	(*R*)-**25a**	31	+12° (1.2, 25)	39
24b	−50	2	(*S*)-**25b**	31	−9° (1.5, 25)	37

a) Nucleophiles **17**, **19**, **22**, or **24a,b** were treated with LDA (1.2 eq) at −78 °C for 1 h, and then reacted with allyl acetate (1.5 eq) in the presence of $[PdCl(\pi\text{–allyl})]_2$ (0.03 eq) and (*S*)-**2d** (0.12 eq). *b*) The enantiomeric excess (e.e.) of the products was determined on the basis of the optical rotations of **18**, **20**, **23**, **25a**, and **25b** obtained (the optical rotation of optically pure (*S*)-(−)-**18**, (*R*)-(−)-**20**, (*R*)-(−)-**23**, (*R*)-(+)-**25a**, and (*S*)-(−)-**25b**: $[\alpha]_D$ −254° ($CHCl_3$), $[\alpha]_D$ −255.6° (EtOH), $[\alpha]_D$ −38.0° (MeOH), $[\alpha]_D$ +29.7° ($CHCl_3$), and $[\alpha]_D$ −22.7° ($CHCl_3$), respectively).

hexanone (**19**), 2-phenylpropanal (**21**)-pyrrolidine enamine (**22**) and ethyl and *tert*-butyl 2-methylacetoacetate (**24a, b**). The palladium-catalyzed allylations of **17**, **19**, **22**, and **24a, b** (the carbanions were generated by treatment with LDA at −78 °C for 1 h) with allyl acetate were carried out in THF at 0—−50 °C for 1—4 h in the presence of $[PdCl(\pi\text{–allyl})]_2$ (0.03 eq) and (*S*)-**2d** (0.12 eq) to give (*S*)-2-allyl-2-(*p*-toluenesulfenyl)cyclohexanone (**18**),[20,21] (*R*)-2-acetyl-2-allylcyclohexanone (**20**),[22] (*R*)-2-methyl-2-phenyl-4-pentenal (**23**),[23] and ethyl and *tert*-butyl (*R*)- and (*S*)-2-allyl-2-methylacetoacetate (**25a**, **25b**)[24] with moderate e.e., respectively. The results obtained are summarized in Table 5. In the case of the acetoacetic esters **24a, b**, the stereochemistry of the products **25a, b**, was not clearly related to the steric bulk of the esters used, ethyl and *tert*-butyl ester.

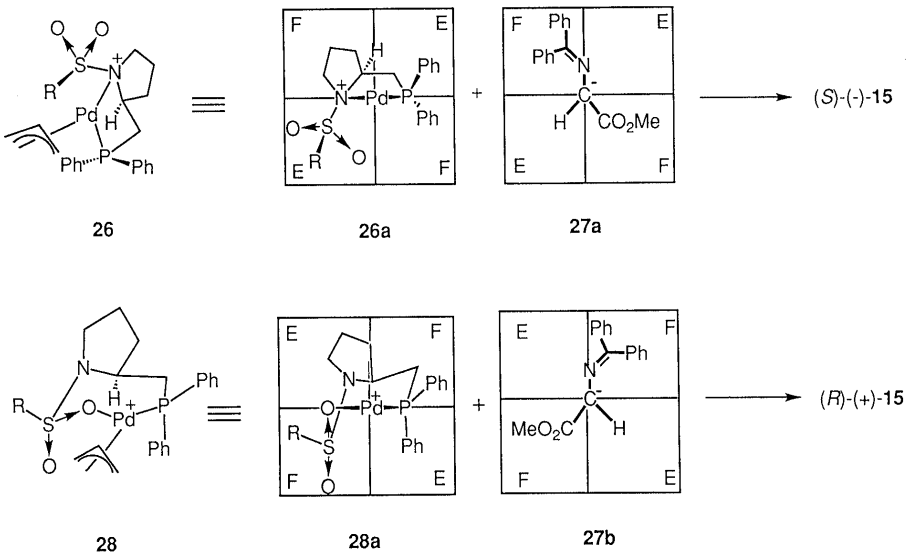
The mechanism of this catalytic asymmetric reaction with chiral phosphinyl amide ligands was next considered on the basis of the stereochemical results obtained.

When the chiral sulfonamides (*S*)-**2d**—**g** were employed as ligands, an intermediary five-membered chiral π–allylpalladium complex **26**, having the *trans* configuration between the sulfonyl group and the substituent (diphenylphosphinomethyl) at the chiral center, would be formed as the thermodynamically most stable intermediate by the coordination of the phosphine group and the nitrogen atom of the amide group to the palladium catalyst. Accordingly, a new asymmetric environment around the π–allylpalladium is created, *via* the formation of an edge (E) and a face (F), by the substituents, the sulfonyl and the diphenyl groups. This intermediate is drawn in **26a**, as seen from the front side of the π–allylpalladium group. The nucleophile, the α-imino ester enolate **27** generated from **14**, would react with **26** by overlapping from the front side of the π–allylpalladium complex **26a** to the upward side in a sterically matched fashion as depicted in **27a**, to furnish (*S*)-(−)-**15**.

The formation of a seven-membered intermediate **28** by the coordination of the sulfonyl oxygen atom to the palladium catalyst would provide a chiral steric environment opposite to that of **26**, as drawn in **28a**, which produces (*R*)-**15**. The reaction path *via* this seven-membered intermediate **28** is in conflict with the experimental results mentioned earlier.

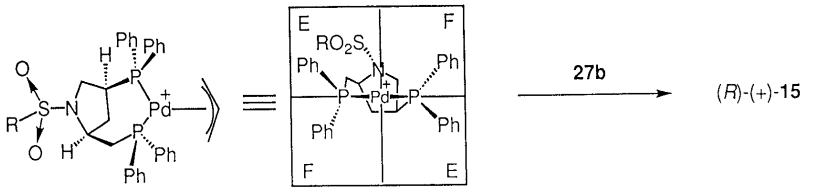
The bidentate phosphine ligands (2*S*,4*S*)-**4a**—**e** would form an intermediary π–allylpalladium complex **29** by the coordination of the diphosphine groups to the palladium catalyst, which creates a new asymmetric environment as shown in **29a** (depicted by E and F). In the same manner as described above, the nucleophile, the α-imino ester enolate **27** generated from **14**, reacts with **29a** by overlapping in the sterically preferred fashion, as depicted in **27b** to produce (*R*)-(+)-**15**.

Similarly, in the case of chiral acyclic sulfonamides,



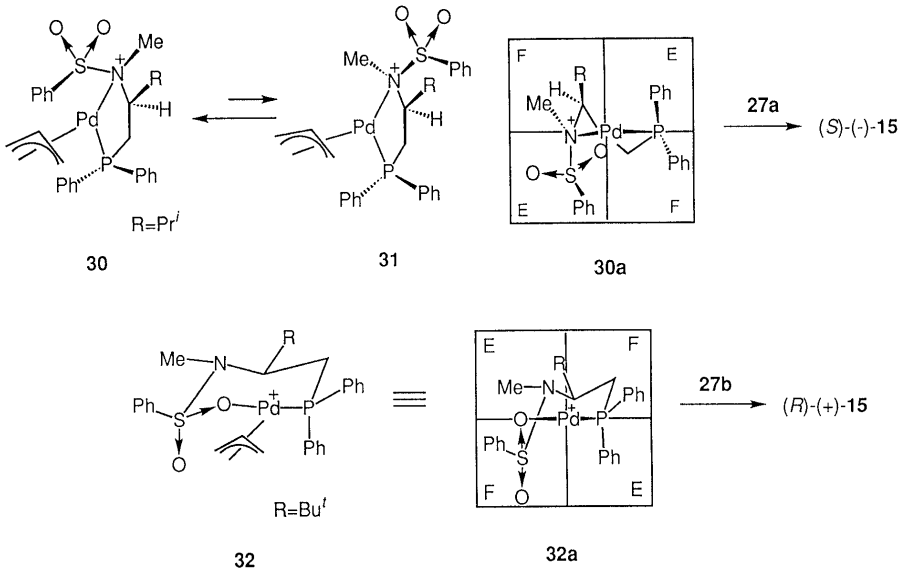
26 26a 27a 28 28a 27b

Chart 6



29 29a

Chart 7



30 31 30a 32 32a

Chart 8

(*S*)-**10a**—**f**, five-membered π–allylpalladium complexes would be formed by the coordination of the phosphine group and the amide nitrogen atom to the palladium catalyst. The reaction of the palladium catalyst with the chiral ligands (*S*)-**10c** derived from (*S*)-valine would produce the thermodynamically most stable **30** having the *trans*-configuration between the isopropyl group and the sulfonyl moiety, in preference to the sterically less stable *cis* intermediate **31**, which presents the asymmetric environment shown in **30a**. The reaction of the enolate **27** with this π-allylpalladium complex proceeds with overlapping of **30a** and **27a** to give (*S*)-(−)-**15**.

In the case of the chiral sulfonamide (*S*)-**10e**, the palladium catalyst can not attack the nitrogen atom of the sulfonamide owing to the steric interference of the bulky *tert*-butyl group. Therefore, the catalyst would react with the sulfonyl oxygen atom to form a seven-membered intermediate **32**, which provides the asymmetric environment drawn in **32a**, affording (*R*)-**15** upon reaction with **27b**.

In these cases, the *N*-phenyl substituent in the sulfonyl group would play a crucial role in determining the stereo-

chemistry of the product and controlling the degree of asymmetric induction. In contrast, the *N*-methyl substituent in the sulfonyl group did not have so great an effect on the asymmetric induction for steric reasons, leading to extremely low e.e. of the product. Presumably, this would stem from the competition of the aforementioned π–allylpalladium complex and other conformers owing to steric effects on the formation of π–allylpalladium intermediates.

Experimental

Infrared (IR) spectra were obtained in the indicated state with a JASCO DR-81 Fourier-transform IR spectrometer. NMR spectra were determined in the indicated solvent with a JEOL JNM PMX-60SI (60 MHz) high-resolution NMR spectrometer; chemical shifts are given in ppm from tetramethylsilane as an internal standard. Splitting patterns are designated as s, singlet; br s: broad singlet; d, doublet; m, multiplet. Mass spectra (MS) were taken on a JEOL JMS-DX 303/JMA-DA 5000 system. Optical rotations were measured with a JASCO DIP-370 polarimeter. Flash column chromatography was performed with Merck Silica gel 60 (230—400 mesh). Thin layer or thick layer plates (preparative TLC) were made of Merck Silica gel 60PF-254 activated by drying at 140 °C for 3.5 h.

(*S*)-*N*-Acetyl-2-(diphenylphosphinomethyl)pyrrolidine (2a) Acetyl chloride (0.03 ml, 0.48 mmol) was added to a solution of (*S*)-2-(diphenylphosphinomethyl)pyrrolidine (**1**)[11] (100 mg, 0.39 mmol) and triethylamine (0.11 ml, 0.79 mmol) in dichloromethane (20 ml) at 0 °C, and the reaction mixture was stirred at 0 °C for 30 min. The reaction solution was diluted with ether, washed with saturated aqueous $NaHCO_3$ and saturated aqueous NaCl, dried over anhydrous Na_2SO_4, and concentrated *in vacuo*. The crude product was subjected to preparative TLC (ether–hexane 2 : 1) to give (*S*)-**2a** (84 mg, 73% yield).

The reaction of (*S*)-**1** (100 mg, 0.39 mmol) with benzoyl chloride (0.06 ml, 0.48 mmol), methanesulfonyl chloride (0.04 ml, 0.48 mmol), ethanesulfonyl chloride (0.05 ml, 0.48 mmol), *p*-toluenesulfonyl chloride (84 mg, 0.48 mmol), or (+)-camphor-10-sulfonyl chloride (120 mg, 0.48 mmol) was carried out using the same procedure as described above to give (*S*)-*N*-benzoyl-, methanesulfonyl-, ethanesulfonyl-, *p*-toluenesulfonyl-, or (+)-camphorsulfonyl-2-(diphenylphosphinomethyl)pyrrolidine (**2b**, **2d**—**g**), respectively.

(*S*)-**2b**: 86% yield. $[\alpha]_D^{26}$ −102.3° (c = 1.9, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1620 (C=O), 1580 (aromatic). NMR (CCl_4) δ: 1.50—2.50 (4H, m, CH_2CH_2), 2.60—4.70 (5H, m, CH_2NCH, CH_2P), 7.00—7.90 (15H, m, $P(C_6H_5)_2$, COC_6H_5). MS m/z: 373 (M^+). Exact mass determination: 373.1596 (Calcd. for $C_{24}H_{24}NOP$: 373.1590).

(*S*)-**2d**: 78% yield. $[\alpha]_D^{27}$ −108.3° (c = 1.2, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1591 (aromatic). NMR (CCl_4) δ: 1.60—2.30 (4H, m, CH_2CH_2), 2.58 (3H, s, SO_2CH_3), 2.65—4.00 (5H, m, CH_2NCH, CH_2P). 7.10—7.70 (10H, m, $P(C_6H_5)_2$). MS m/z: 347 (M^+). Exact mass determination: 347.1055 (Calcd for $C_{18}H_{22}NO_2PS$: 347.11090).

(*S*)-**2e**: 73% yield. $[\alpha]_D^{27}$ −11.5° (c = 1.1, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1591 (aromatic). NMR (CCl_4) δ: 1.30 (3H, t, J = 6 Hz, $CH_2C\underline{H}_3$), 1.40—2.30 (4H, m, CH_2CH_2), 2.85 (2H, q, J = 6 Hz, $C\underline{H}_2CH_3$), 3.10—4.80 (5H, m, CH_2NCH, CH_2P). 7.10—7.70 (10H, m, $P(C_6H_5)_2$). MS m/z: 361 (M). Exact mass determination: 361.1266 (Calcd for $C_{19}H_{24}NO_2PS$: 361.12660).

(*S*)-**2f**: 54% yield. $[\alpha]_D^{27}$ +3.4° (c = 1.2, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1600 (aromatic). NMR (CCl_4) δ: 1.60—2.30 (4H, m, CH_2CH_2), 2.40 (3H, s, $C\underline{H}_3C_6H_4$), 2.80—3.80 (5H, m, CH_2NCH, CH_2P). 7.00—8.10 (14H, m, $CH_3C_6\underline{H}_4$, $P(C_6H_5)_2$). MS m/z: 423 (M^+). Exact mass determination: 423.1421 (Calcd for $C_{24}H_{26}NO_2PS$: 423.14220).

(*S*)-**2g**: 43% yield. $[\alpha]_D^{28}$ −60.6° (c = 1.4, EtOH). IR ν_{max}^{film} cm^{-1}: 1740 (C=O), 1580 (aromatic). NMR (CCl_4) δ: 0.70, 1.20 (6H, s, s, $(CH_3)_2$), 1.20—2.80 (11H, m, 5 × CH_2, CH), 2.80—4.00 (7H, m, CH_2S, CH_2NCH, CH_2P), 7.00—7.70 (10H, m, $P(C_6H_5)_2$). MS m/z: 483 (M^+). Exact mass determination: 483.1997 (Calcd for $C_{27}H_{34}NO_3PS$: 483.19970).

(2*S*,4*S*)-*N*-Methanesulfonyl-4-(diphenylphosphino)-2-(diphenylphosphinomethyl)pyrrolidine (4d) A solution of methanesulfonyl chloride (38 mg, 0.33 mmol) in dichloromethane (2 ml) was added at 0 °C to a solution of (2*S*,4*S*)-4-(diphenylphosphino)-2-(diphenylphosphinomethyl)pyrrolidine (**3**)[15] (100 mg, 0.22 mmol) and triethylamine (0.09 ml, 0.66 mmol) in dichloromethane (20 ml) and the reaction mixture was stirred for 30 min. It was then diluted with ether, washed with saturated aqueous $NaHCO_3$ and saturated aqueous NaCl, dried over anhydrous Na_2SO_4, and concentrated *in vacuo*. The crude product was subjected to preparative TLC (ether–hexane 2 : 1) to give (2*S*,4*S*)-**4d** (68 mg, 58% yield).

(2*S*,4*S*)-**4d**: 58% yield. $[\alpha]_D^{27}$ −40.4° (c = 1.6, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1590 (aromatic). NMR (CCl_4) δ: 1.60—2.60 (2H, m, CH_2CHP), 2.70 (3H, s, CH_3SO_2), 3.30—4.30 (6H, m, CH_2NCH, CHP, CH_2P), 7.10—7.70 (20H, m, 2 × $P(C_6H_5)_2$). MS m/z: 531 (M^+). Exact mass determination: 531.1551 (Calcd for $C_{30}H_{31}NO_2P_2S$: 531.15510).

The reaction of (2*S*,4*S*)-**3** (100 mg, 0.22 mmol) with (+)-camphor-10-sulfonyl chloride (83 mg, 0.33 mmol) was carried out using the same procedure as described above to give (2*S*,4*S*)-*N*-(+)-camphor-10-sulfonyl-4-(diphenylphosphino)-2-(diphenylphosphinomethyl)pyrrolidine (**4e**).

(*S*)-**4e**: 40% yield. $[\alpha]_D^{25}$ +5.6° (c = 0.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1740 (C=O), 1600 (aromatic). NMR (CCl_4) δ: 0.70, 1.20 (6H, s, s, $(CH_3)_2$), 1.20—2.80 (9H, m, 4 × CH_2, CH), 2.80—4.00 (8H, m, CH_2S, CH_2NCH, CHP, CH_2P), 7.00—8.10 (20H, m, 2 × P $(C_6H_5)_2$). MS m/z: 667 (M^+). Exact mass determination: 667.2438 (Calcd for $C_{39}H_{43}NO_3P_2S$: 667.24380).

***N*-Benzenesulfonyl-(*S*)-alanine Ethyl Ester (6a)** A solution of benzenesulfonyl chloride (1.70 g, 9.45 mmol) in dichloromethane (3 ml) was added at 0 °C to a solution of (*S*)-alanine ethyl ester (**5a**) (1.00 g, 6.30 mmol) and triethylamine (2.6 ml, 18.9 mmol) in dichloromethane (20 ml) and the reaction mixture was stirred at 0 °C for 30 min. It was then diluted with ether, washed with 10% aqueous HCl and saturated aqueous NaCl, dried over anhydrous Na_2SO_4, and concentrated *in vacuo*. The crude product was subjected to preparative TLC (ether–hexane 2 : 1) to give (*S*)-**6a** (1.20 g, 90% yield).

(*S*)-**6a**: $[\alpha]_D^{27}$ +9.3° (c = 1.3, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3283 (NH), 1738 (ester), 1590 (aromatic). NMR (CCl_4) δ: 1.10 (3H, t, J = 7 Hz, $CO_2CH_2C\underline{H}_3$), 1.38 (3H, d, J = 6 Hz, CH_3), 3.60—4.25 (3H, m, CHN, $CO_2C\underline{H}_2CH_3$), 5.45—5.90 (1H, m, NH), 7.20—8.10 (5H, m, C_6H_5). MS m/z: 257 (M^+). Exact mass determination: 257.0722 (Calcd for $C_{11}H_{15}NO_4S$: 257.07220).

The reactions of (*S*)-valine ethyl ester (**5b**) (1.00 g, 6.89 mmol) with methanesulfonyl chloride (1.18 g, 10.33 mmol) or benzenesulfonyl chloride (1.00 g, 6.89 mmol), (*S*)-*tert*-leucine ethyl ester (**5c**) (1.00 g, 5.11 mmol) with methanesulfonyl chloride (0.70 g, 6.13 mmol) or benzenesulfonyl chloride (1.08 g, 6.13 mmol), and (*S*)-phenylalanine ethyl ester (**5d**) (1.00 g, 5.18 mmol) with benzenesulfonyl chloride (1.37 g, 7.76 mmol) were carried out using the same procedure as described above to give *N*-methanesulfonyl- or benzenesulfonyl-(*S*)-valine ethyl ester (**6b**, **c**), *N*-methanesulfonyl- or benzenesulfonyl-(*S*)-*tert*-leucine ethyl ester (**6d**, **e**) and *N*-benzenesulfonyl-(*S*)-phenylalanine ethyl ester (**6f**), respectively.

(*S*)-**6b**: 80% yield. $[\alpha]_D^{27}$ −8.5° (c = 1.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3300 (NH), 1740 (ester). NMR (CCl_4) δ: 0.95 (6H, t, J = 6 Hz, $CH(CH_3)_2$), 1.30 (3H, t, J = 7 Hz, $CO_2CH_2C\underline{H}_3$), 1.80—2.50 (1H, m, $C\underline{H}(CH_3)_2$), 2.85 (3H, s, CH_3SO_2), 3.70—4.00 (1H, m, CHN), 4.20 (2H, q, J = 7 Hz, $CO_2C\underline{H}_2CH_3$), 5.30—5.70 (1H, m, NH). MS m/z: 223 (M^+). Exact mass determination: 223.0878 (Calcd for $C_8H_{17}NO_4S$: 223.08780).

(*S*)-**6c**: 99% yield. $[\alpha]_D^{27}$ +27.2° (c = 1.6, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3400 (NH), 1740 (ester), 1590 (aromatic). NMR (CCl_4) δ: 0.80—1.30 (9H, m, $CH(C\underline{H}_3)_2$, $CO_2CH_2C\underline{H}_3$), 1.50—2.40 (1H, m, $C\underline{H}(CH_3)_2$), 3.50—4.20 (3H, m, CHN, $CO_2C\underline{H}_2CH_3$), 5.30—5.70 (1H, m, NH), 7.20—7.90 (5H, m, $SO_2C_6H_5$), MS m/z: 285 (M^+). Exact mass determination: 285.1035 (Calcd for $C_{13}H_{19}NO_4S$: 285.1035).

(*S*)-**6d**: 95% yield. $[\alpha]_D^{27}$ −1.0° (c = 2.1, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3283 (NH), 1732 (ester). NMR (CCl_4) δ: 1.00 (9H, s, $C(CH_3)_3$), 1.30 (3H, t, J = 7 Hz, $CO_2CH_2C\underline{H}_3$), 2.85 (3H, s, SCH_3), 3.50—3.80 (1H, m, CHN), 4.20 (2H, q, J = 7 Hz, $CO_2C\underline{H}_2CH_3$), 5.30—6.10 (1H, m, NH). MS m/z: 237 (M^+). Exact mass determination: 237.1035 (Calcd for $C_9H_{19}NO_4S$: 237.10350).

(*S*)-**6e**: 95% yield. $[\alpha]_D^{27}$ +38.3° (c = 2.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3331 (NH), 1732 (ester). NMR (CCl_4) δ: 0.85—1.20 (12H, m, $C(CH_3)_3$, $CO_2CH_2C\underline{H}_3$), 3.30—4.20 (3H, m, CHN, $CO_2C\underline{H}_2CH_3$), 4.80—5.40 (1H, m, NH), 7.30—7.90 (5H, m, C_6H_5). MS m/z: 299 (M^+). Exact mass determination: 299.1192 (Calcd for $C_{14}H_{21}NO_4S$: 299.11910).

(*S*)-**6f**: 83% yield. $[\alpha]_D^{27}$ +15.7° (c = 0.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3325—3300 (NH), 1739 (ester), 1600 (aromatic). NMR (CCl_4) δ: 1.08 (3H, t, J = 7 Hz, $CO_2CH_2C\underline{H}_3$), 2.80—3.40 (2H, m, $C\underline{H}_2C_6H_5$), 3.60—4.60 (3H, m, CHN, $CO_2C\underline{H}_2CH_3$), 4.80—5.20 (1H, m, NH),

6.85—8.00 (10H, m, C_6H_5S, $CH_2C_6\underline{H}_5$). MS *m/z*: 333 (M^+). Exact mass determination: 333.1035 (Calcd for $C_{17}H_{19}NO_4S$: 333.10350).

***N*-Benzenesulfonyl-*N*-methyl-(*S*)-alanine Ethyl Ester (7a)** A mixture of (*S*)-**6a** (1.00 g, 4.40 mmol), methyl iodide (6.0 ml, 5.02 mmol), and K_2CO_3 (0.6 g, 5.02 mmol) in acetone (60 ml) was stirred at room temperature for 12 h. It was then concentrated *in vacuo* and the residue was dissolved in ether. The ethereal layer was washed successively with 10% aqueous HCl, saturated aqueous $NaHCO_3$, saturated aqueous $Na_2S_2O_3$, and saturated aqueous NaCl, dried over anhydrous Na_2SO_4, and concentrated *in vacuo*. The crude product was subjected to preparative TLC (ether–hexane 1 : 1) to give (*S*)-**7a** (1.00 g, 96% yield).

(*S*)-**7a**: $[\alpha]_D^{25}$ −25.3° (*c* = 1.2, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1738 (ester), 1590 (aromatic). NMR (CCl_4) δ: 1.07 (3H, t, *J* = 7 Hz, $CO_2CH_2C\underline{H}_3$), 1.34 (3H, d, *J* = 6 Hz, CH_3), 2.76 (3H, s, CH_3N), 3.85 (2H, q, *J* = 7 Hz, $CO_2C\underline{H}_2CH_3$), 4.65 (1H, q, *J* = 6 Hz, CHN), 7.00—8.10 (5H, m, C_6H_5). MS *m/z*: 271 (M^+). Exact mass determination: 271.0879 (Calcd for $C_{12}H_{17}NO_4S$: 271.08780).

The *N*-methylations of (*S*)-**6b—f** with methyl iodide were carried out using the same procedure to give *N*-methyl-*N*-methanesulfonyl- or benzenesulfonyl-(*S*)-valine ethyl ester (**7b, c**), *N*-methyl-*N*-methanesulfonyl- or benzenesulfonyl-(*S*)-*tert*-leucine ethyl ester (**7d, e**), and *N*-benzenesulfonyl-*N*-methyl-(*S*)-phenylalanine-ethyl ester (**7f**), respectively.

(*S*)-**7b**: 78% yield. $[\alpha]_D^{27}$ −47.0° (*c* = 1.4, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1736 (ester). NMR (CCl_4) δ: 0.80—1.10 (6H, m, $CH(C\underline{H}_3)_2$), 1.30 (3H, t, *J* = 7 Hz, $CO_2CH_2C\underline{H}_3$), 1.80—2.50 (1H, m, $C\underline{H}(CH_3)_2$), 2.70—2.90 (6H, br s, CH_3N, CH_3SO_2), 3.90—4.40 (3H, m, CHN and $CO_2C\underline{H}_2CH_3$). MS *m/z*: 237 (M^+). Exact mass determination: 237.1035 (Calcd for $C_9H_{19}NO_4S$: 237.10350).

(*S*)-**7c**: 80% yield. $[\alpha]_D^{27}$ −10.4° (*c* = 1.3, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1740 (ester), 1590 (aromatic). NMR (CCl_4) δ: 0.80—1.30 (9H, m, $CH(C\underline{H}_3)_2$, $CO_2CH_2C\underline{H}_3$), 1.50—2.40 (1H, m, $C\underline{H}(CH_3)_2$), 2.80 (3H, s, CH_3N), 3.50—4.20 (3H, m, CHN, $CO_2C\underline{H}_2CH_3$), 7.20—7.90 (5H, m, $SO_2C_6H_5$). MS *m/z*: 299 (M^+). Exact mass determination: 299.1192 (Calcd for $C_{14}H_{21}NO_4S$: 299.11910).

(*S*)-**7d**: 85% yield. $[\alpha]_D^{27}$ −27.1° (*c* = 1.3, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1736 (ester). NMR (CCl_4) δ: 1.12 (9H, s, $C(CH_3)_3$), 1.35 (3H, t, *J* = 7 Hz, $CO_2CH_2C\underline{H}_3$), 2.65 (3H, s, CH_3N), 2.95 (3H, s, CH_3SO_2), 3.90—4.40 (3H, m, CHN, $CO_2C\underline{H}_2CH_3$). MS *m/z*: 251 (M^+). Exact mass determination: 251.1191 (Calcd for $C_{10}H_{21}NO_4S$: 251.11910).

(*S*)-**7e**: 71% yield. $[\alpha]_D^{27}$ −33.4° (*c* = 1.8, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1736 (ester), 1588 (aromatic). NMR (CCl_4) δ: 0.70—1.20 (12H, m, $C(CH_3)_3$, $CO_2CH_2C\underline{H}_3$), 2.78 (3H, s, NCH_3), 3.60—4.20 (3H, m, CHN, $CO_2C\underline{H}_2CH_3$), 7.30—8.00 (5H, m, SC_6H_5). MS *m/z*: 313 (M^+). Exact mass determination: 313.1348 (Calcd for $C_{15}H_{23}NO_4S$: 313.13450).

(*S*)-**7f**: 78% yield. $[\alpha]_D^{25}$ −14.9° (*c* = 1.0, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1738 (ester), 1600 (aromatic). NMR (CCl_4) δ: 1.08 (3H, t, *J* = 7 Hz, $CO_2CH_2C\underline{H}_3$), 2.70—3.30 (5H, m, $C\underline{H}_2C_6H_5$, CH_3N), 3.95 (2H, q, *J* = 7 Hz, $CO_2C\underline{H}_2CH_3$), 4.60—5.20 (1H, m, CHN), 7.00—7.70 (10H, m, C_6H_5S, $CH_2C_6\underline{H}_5$). MS *m/z*: 347(M^+). Exact mass determination: 347.11910 (Calcd for $C_{18}H_{21}NO_4S$: 347.11910).

***N*-Benzenesulfonyl-*N*-methyl-(*S*)-alaninol (8a)** $LiAlH_4$ (91 mg, 2.40 mmol) was added at 0 °C to a solution of (*S*)-**7a** (500 mg, 1.60 mmol) in THF (100 ml), and the reaction mixture was stirred at 0 °C for 30 min. The reaction was quenched by adding H_2O (3 ml) and 10% aqueous NaOH (0.9 ml), and the mixture was heated under reflux for 1 h. After cooling, the mixture was filtered and the filtrate was concentrated *in vacuo*. The crude product was subjected to preparative TLC (ether–hexane 1 : 1) to give (*S*)-**8a** (378 mg, 89% yield).

(*S*)-**8a**: $[\alpha]_D^{25}$ +15.0° (*c* = 2.1, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3528 (OH), 1590 (aromatic). NMR (CCl_4) δ: 0.85 (3H, d, *J* = 6 Hz, CH_3), 2.70 (3H, s, CH_3N), 3.30—3.40 (1H, br s, OH), 3.40—3.50 (2H, m, $C\underline{H}_2OH$), 3.70—4.40 (1H, m, CHN), 7.20—8.00 (5H, m, SC_6H_5). MS *m/z*: 229 (M^+). Exact mass determination: 229.0772 (Calcd for $C_{10}H_{15}NO_3S$: 229.0772).

The $LiAlH_4$ reduction of (*S*)-**7b—f** and (*S*)-**6b, c** was carried out using the same procedure as described above to give *N*-methyl-*N*-methanesulfonyl- or benzenesulfonyl-(*S*)-valinol (**8b, c**), *N*-methyl-*N*-methanesulfonyl- or benzenesulfonyl-(*S*)-*tert*-leucinol (**8d, e**), *N*-benzenesulfonyl-*N*-methyl-(*S*)-phenylalaninol (**8f**), and *N*-methanesulfonyl- or benzenesulfonyl-(*S*)-valinol (**14a, b**), respectively.

(*S*)-**8b**: 80% yield. $[\alpha]_D^{25}$ −0.9° (*c* = 2.3, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3528 (OH). NMR (CCl_4) δ: 0.80—1.10 (6H, m, $CH(C\underline{H}_3)_2$), 1.30—2.00 (1H, m, $C\underline{H}(CH_3)_2$), 2.80 (3H, s, CH_3N), 2.93 (4H, s, CH_3S), 3.30—4.10 (4H, m, CHN, CH_2OH). MS *m/z*: 195(M^+). Exact mass determination: 195.0929 (Calcd for $C_7H_{17}NO_3S$: 195.09290).

(*S*)-**8c**: 90% yield. $[\alpha]_D^{25}$ +17.2° (*c* = 1.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3500 (OH), 1590 (aromatic). NMR (CCl_4) δ: 0.90—1.00 (6H, m, $CH(C\underline{H}_3)_2$), 1.30—2.00 (1H, m, $C\underline{H}(CH_3)_2$), 2.83 (3H, s, CH_3N), 2.45—4.00 (4H, m, CHN, CH_2OH), 7.40—8.00 (5H, m, $SO_2C_6H_5$). MS *m/z*: 257 (M^+). Exact mass determination: 257.1086 (Calcd for $C_{12}H_{19}NO_3S$: 257.10860).

(*S*)-**8d**: 88% yield. $[\alpha]_D^{25}$ +16.6° (*c* = 2.2, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3500 (OH). NMR (CCl_4) δ: 1.18 (9H, s, $C(CH_3)_3$), 2.00—2.30 (1H, br s, OH), 2.80—3.10 (6H, br s, CH_3N, CH_3SO_2), 3.60—4.10 (3H, m, CHN, $C\underline{H}_2OH$). MS *m/z*: 209 (M^+). Exact mass determination: 209.1086 (Calcd $C_8H_{19}NO_3S$: 209.10860).

(*S*)-**8e**: 82% yield. $[\alpha]_D^{25}$ −12.1° (*c* = 1.7, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3530 (OH), 1588 (aromatic). NMR (CCl_4) δ: 0.70—1.10 (9H, br s, $C(CH_3)_3$), 2.78 (3H, s, NCH_3), 3.35—4.00 (4H, m, CH_2OH, CHN), 7.20—8.00 (5H, m, SC_6H_5). MS *m/z*: 271 (M^+). Exact mass determination: 271.12420 (Calcd for $C_{13}H_{21}NO_3S$: 271.12420).

(*S*)-**8f**: 85% yield. $[\alpha]_D^{25}$ −63.6° (*c* = 1.1, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 3325 (OH), 1600 (aromatic). NMR (CCl_4) δ: 1.80—2.00 (1H, br s, OH), 2.30—3.00 (5H, m, $C\underline{H}_2C_6H_5$, CH_3N), 3.50—3.70 (2H, m, $C\underline{H}_2OH$), 3.90—4.60 (1H, m, CHN), 6.80—7.70 (10H, m, C_6H_5S, $CH_2C_6\underline{H}_5$). MS *m/z*: 305 (M^+). Exact mass determination: 305.1085 (Calcd for $C_{16}H_{19}NO_3S$: 305.10860).

***(S)*-*N*-Benzenesulfonyl-*N*-methyl-1-(diphenylphosphino)-2-propylamine (10a)** A solution of methanesulfonyl chloride (2.29 g, 0.020 mol) in dichloromethane (10 ml) was added at 0 °C to a solution of (*S*)-**8a** (3.80 g, 0.017 mol) and triethylamine (2.8 ml, 0.020 mol). The reaction mixture was stirred at 0 °C for 4 h, then diluted with ether and filtered. The filtrate was concentrated *in vacuo* to give *N*-benzenesulfonyl-*N*-methyl-(*S*)-alaninol methanesulfonate (**9a**). The methanesulfonate (*S*)-**9a** obtained above was used without further purification. A solution of diphenylphosphinyl chloride (370 mg, 1.68 mmol) in THF (5 ml) was added to a mixture of lithium (26 mg, 3.71 mmol) in THF (20 ml) under an atmosphere of nitrogen and the whole was heated under reflux for 3 h. A solution of (*S*)-**9a** obtained above in THF (10 ml) was added to the above mixture cooled to −20 °C and the reaction mixture was diluted with benzene and filtered through Celite. The filtrate was concentrated *in vacuo* and the residue was subjected to preparative TLC (ether–hexane 2 : 1) to give (*S*)-*N*-benzenesulfonyl-*N*-methyl-1-(diphenylphosphino)-2-propylamine (**10a**) (190 mg, 39% yield).

(*S*)-**10a**: $[\alpha]_D^{25}$ −8.9° (*c* = 1.7, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1599 (aromatic). NMR (CCl_4) δ: 0.95 (3H, d, *J* = 6 Hz, CH_3), 2.30—2.50 (2H, m, CH_2P), 2.60 (3H, s, CH_3N), 4.00—4.50 (1H, m, CHN), 7.00—8.10 (15H, m, SC_6H_5, $P(C_6H_5)_2$). MS *m/z*: 397 (M^+). Exact mass determination: 397.1266 (Calcd for $C_{22}H_{24}NO_2PS$: 397.12660).

The methanesulfonylation of (*S*)-**8b—f** followed by the phosphinylation of the mesylates (*S*)-**9b—f** was carried out using the same procedure as mentioned above to give (*S*)-*N*,3-dimethyl-*N*-methanesulfonyl- or benzenesulfonyl-1-(diphenylphosphino)-2-butylamine (**10b**[16] or **10c**), (*S*)-*N*-methanesulfonyl- or benzenesulfonyl-1-(diphenylphosphino)-*N*,3, 3-trimethyl-2-butylamine (**10d, e**), (*S*)-*N*-benzenesulfonyl-*N*-methyl-3-phenyl-1-(diphenylphosphino)-2-propylamine (**10f**), and (*S*)-*N*, 3-dimethyl-*N*-methanesulfonyl- or benzenesulfonyl-1-(diphenylphosphino)-2- butylamine (**13a, b**),[16] respectively.

(*S*)-**10b**: 45% yield. $[\alpha]_D^{25}$ +71.5° (*c* = 1.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1590 (aromatic). NMR (CCl_4) δ: 0.80—1.20 (6H, m, $CH(C\underline{H}_3)_2$), 1.50—2.70 (3H, m, $C\underline{H}(CH_3)_2$, CH_2P), 2.75 (3H, s, CH_3N), 2.90 (3H, s, CH_3S), 7.10—7.90 (10H, m, $P(C_6H_5)_2$). MS *m/z*: 363 (M^+). Exact mass determination: 363.1306 (Calcd for $C_{19}H_{26}NO_2PS$: 363.1307).

(*S*)-**10c**: 85% yield. $[\alpha]_D^{25}$ +41.4° (*c* = 2.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1590 (aromatic). NMR (CCl_4) δ: 0.70—1.10 (6H, m, $CH(C\underline{H}_3)_2$), 2.60—2.50 (3H, m, $C\underline{H}(CH_3)_2$, CH_2P), 2.63 (3H, s, CH_3N), 2.45—4.05 (1H, m, CHN), 6.90—7.70 (15H, m, $SO_2C_6H_5$, $P(C_6H_5)_2$). MS *m/z*: 425 (M^+). Exact mass determination: 425.1463 (Calcd for $C_{24}H_{28}NO_2PS$: 425.14630).

(*S*)-**10d**: 19% yield. $[\alpha]_D^{25}$ −53.2° (*c* = 1.1, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1590 (aromatic). NMR (CCl_4) δ: 0.98 (9H, s, $C(C\underline{H}_3)_3$), 1.70—2.70 (2H, m, CH_2P), 2.93 (3H, s, CH_3N), 3.05 (3H, s, CH_3SO_2), 3.40—4.20 (1H, m, CHN), 7.10—7.70 (10H, m, $P(C_6H_5)_2$). MS *m/z*: 377(M^+). Exact mass determination: 377.1578 (Calcd for $C_{20}H_{28}NO_2PS$: 377.15790).

(*S*)-**10e**: 24% yield. $[\alpha]_D^{25}$ +113.5° (*c* = 1.7, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1588 (aromatic). NMR (CCl_4) δ: 0.70—1.30 (9H, m, $C(CH_3)_3$), 1.50—2.70 (2H, m, CH_2P), 2.75 (3H, s, NCH_3), 3.60—4.40 (1H, m,

CHN), 6.80—8.00 (15H, m, SC_6H_5, $P(C_6H_5)_2$). MS *m/z*: 439(M^+). Exact mass determination: 439.1735 (Calcd for $C_{25}H_{30}NO_2PS$: 439.17350).

(*S*)-**10f**: 39% yield. $[\alpha]_D^{25}$ −36.9° (*c* = 1.5, $CHCl_3$). IR ν_{max}^{film} cm^{-1}: 1600 (aromatic). NMR (CCl_4) δ: 2.00—2.40 (2H, m, CH_2P), 2.50—3.30 (5H, m, $CH_2C_6H_5$, CH_3N), 4.00—4.60 (1H, m, CHN), 6.70—8.00 (20H, m, C_6H_5S, $CH_2C_6H_5$, $P(C_6H_5)_2$). MS *m/z*: 473 (M^+). Exact mass determination: 473.1578 (Calcd for $C_{28}H_{28}NO_2PS$: 473.15790).

Palladium-Catalyzed Asymmetric Allylations Using (*S*)-2a—h, (*S*)-4a—d, (*S*)-10a—f, and (*S*)-13a, b as Chiral Ligands. General Procedure A 25 ml two-necked flask equipped with a septem inlet and a magnetic stirring bar was flushed with nitrogen and maintained under a positive pressure of nitrogen. A solution of isopropylamine (0.07 ml, 0.47 mmol) in THF (1 ml) was added. A 1.16 M hexane solution of butyllithium (2.83 ml, 0.47 mmol) was then added at 0 °C. The mixture was stirred at 0 °C for 15 min, then the flask was cooled to −78 °C. A solution of diphenyl ketimine **14** (100 mg, 0.39 mmol) in THF (1 ml) was added to the above solution and the mixture was stirred at −78 °C for 1 h. Another 25ml two-necked flask equipped with a septem inlet and a magnetic stirring bar, and containing di-μ-chlorobis(π-allyl) dipalladium ($[PdCl(CH_2=CH-CH_2)]_2$] (4.3 mg, 0.01 mmol), was flushed with nitrogen, and maintained under a positive pressure of nitrogen. A solution of allyl acetate (0.06 ml, 0.59 mmol) and (*S*)-**10a—f**, or (*S*)-**13a, b** (0.01 mmol) in THF (3 ml) was added at 0 °C to the above solution and the mixture was stirred at 0 °C for 30 min. This solution was added to the above solution and the reaction mixture was stirred under the conditions listed in Tables 1—4.

The reaction solution was diluted with ether and this solution was washed with saturated aqueous NH_4Cl and saturated aqueous NaCl, dried over anhydrous Na_2SO_4, and concentrated *in vacuo*. The crude product was subjected to preparative TLC (ether–hexane 2 : 1) to give methyl (*R*)-2-amino-4-pentenoate diphenyl ketimine (**15**).[18] The results obtained are listed in Tables 1—4.

The asymmetric allylation of ethyl or *tert*-butyl 2-methylacetoacetate (**24a, b**) (100 mg, 0.69 mmol), 2-*p*-toluenesulfenylcyclohexanone (**17**) (100 mg, 0.45 mmol), 2-acetylcyclohexanone (**19**) (100 mg, 0.71 mmol), or 2-phenylpropanal (**21**)-pyrrolidine enamine **22** (100 mg, 0.74 mmol), was carried out using the same procedure as described above to give (*S*)-(−)-2-allyl-2-*p*-toluenesulfenylcyclohexanone (**18**),[20,21] (*R*)-(−)-2-acetyl-2-allylcyclohexanone (**20**),[22] (*R*)-(−)-2-methyl-2-phenyl-4-pentenol (**23**),[23] and ethyl or *tert*-butyl (*R*)-(+)- or (*S*)-(−)-2-allyl-2-methylacetoacetate (**25a, b**),[24] respectively. The results obtained are listed in Table 5.

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