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Asymmetric Allylation with a New Chiral Allylating Agent Prepared from Tin(II) Triflate, Chiral Diamine, and Allylaluminum

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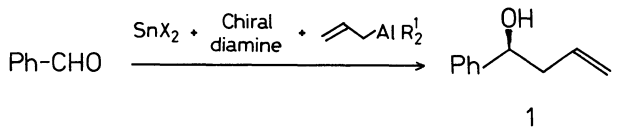
A chiral allylating agent, readily generated from tin(II) trifluoromethanesulfonate (tin(II) triflate), chiral diamines derived from (S)-proline and allylaluminum, is efficiently employed in the asymmetric allylation of aldehydes and an epoxide. Reaction of a chiral 2-methyl-2-propenylating (methallylating) agent with aldehydes also proceeds smoothly to afford the corresponding homoallylic alcohols in good yields with high enantioselectivities. According to a similar procedure, asymmetric propargylation of aldehydes affords homopropargylic alcohols in good optical purities.

Asymmetric synthesis is one of the most important approaches for producing optically active substances and recently a wide variety of methods have been reported by many research groups.[1] Asymmetric synthesis may be divided into two distinct sections; those processes in which, (i) the chiral auxiliary is incorporated into either (or both) reacting partners (ii) the chiral auxiliary is not covalently bonded to either of the reactants. Incorporation of a chiral source into either (or both) of the reactants has met with great success and many examples have been reported.[1] However, incorporation of the chiral auxiliary into reactants and the subsequent necessary removal of it from the reaction products is a disadvantage of this method.

The latter of these two approaches should be a very convenient method for asymmetric synthesis and seems to warrant concentrated investigation, however, so far it has not met with much success.[1] Utilization of metal chelates for inter- or intramolecular interactions seems to be one of the solutions leading to successful asymmetric synthesis of this type, in which the chiral auxiliary is not covalently bonded to the reactants. During the course of our synthetic investigation, we found that utilization of the chelation of chiral diamines derived from (*S*)-proline to tin(II) enolate enables a highly efficient asymmetric cross aldol reaction.[2] Thus, divalent tin, having vacant d orbitals, is able to accept a bidentate ligand, and chiral diamines are efficient ligands in certain asymmetric reactions by virtue of forming a rigid five-five membered fused ring chelate in the transition state. In an extension of this concept, we have reported a convenient and efficient asymmetric acylation[3] and asymmetric reduction[4] using a new chiral reducing agent prepared from tin(II) chloride, chiral diamine derived from (*S*)-proline and diisobutylaluminum hydride as the reductant. It was considered that this new method for asymmetric reduction should be applicable to asymmetric carbon-carbon bond forming reactions and hence we examined asymmetric allylation of carbonyl compounds utilizing tin(II) compound, chiral diamine and allylating reagent. The asymmetric allylation reaction is useful for asymmetric carbon-carbon bond formation,[5] and several successful methods have been reported using chiral allylic organometallics as the allylating agent[6] or , using chiral acetals as chiral acceptors.[7] However, in these reactions tedious procedures for the attachment and removal of the chiral sources are necessary. Hence a simple procedure for the asymmetric allylation utilizing chiral chelating agents is desirable. We investigated the effective combination of tin(II) compound, chiral diamine and allylating reagent, and found that a new chiral allylating agent prepared by the treatment of tin(II) triflate, chiral diamine derived from (*S*)-proline and allyldialkylaluminum as the allylating reagent is efficient for asymmetric allylation of aldehydes, as we have briefly reported in a preliminary communication.[8] We now describe in full the results of our investigation on asymmetric allylation with this new reagent and the application of the present method to asymmetric methallylation and propargylation.

Results and Discussion

Asymmetric Allylation of Aldehydes with Chiral Allylating Agent. Allyldialkylaluminum is easily prepared by treatment of allylmagnesium bromide with dialkylaluminum chloride at 0 °C in Et_2O,[9] followed by exchange of solvent from Et_2O to CH_2Cl_2. This solution of allyldialkylaluminum in CH_2Cl_2 was employed in the reactions described below. In the first place, we examined suitable reaction conditions using benzaldehyde as a model substrate, and these results are summarized in Table 1.



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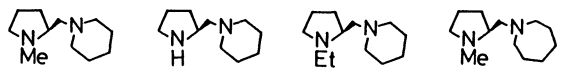
The reactions were carried out as follows: To a suspension of tin(II) compound in CH_2Cl_2 was added chiral diamine in CH_2Cl_2 at room temperature. After the solution was cooled to −78 °C, allyldialkylaluminum was added, followed by the addition of benzalde-

Table 1. Asymmetric Allylation of Benzaldehyde with Chiral Allylating Agent under Various Conditions[a)]

Entry No.	R^1	SnX_2	Chiral diamine	Molar ratio[b)]	Solvent	Yield[c)]/%	% ee
1	Et	—	**2**	A	CH_2Cl_2	62	0
2	Et	$SnCl_2$	**2**	A	CH_2Cl_2	76	0
3	Et	$SnBr_2$	**2**	A	CH_2Cl_2	85	0
4	Et	SnF_2	**2**	A	CH_2Cl_2	71	10[d)]
5	Et	$Sn(OAc)_2$	**2**	A	CH_2Cl_2	82	0
6	Et	$Sn(OTf)_2$	**2**	A	CH_2Cl_2	81	42[d)]
7	Et	$Sn(OTf)_2$	**2**	A	$PhCH_3$	69	0
8	Et	$Sn(OTf)_2$	**2**	A	THF	64	4[d)]
9	Et	$Sn(OTf)_2$	**2**	A	CH_2Cl_2	83	52[d)]
10	Et	$Sn(OTf)_2$	**2**	B	CH_2Cl_2	75	61[d)]
11	Et	$Sn(OTf)_2$	**3**	B	CH_2Cl_2	88	3[d)]
12	Et	$Sn(OTf)_2$	**4**	B	CH_2Cl_2	65	21[d)]
13	Et	$Sn(OTf)_2$	**5**	B	CH_2Cl_2	84	8[d)]
14	Ph	$Sn(OTf)_2$	**2**	B	CH_2Cl_2	77	59[d)]
15	Bu^i	$Sn(OTf)_2$	**2**	B	CH_2Cl_2	91	84[e)] 82[d)]
16	Bu^i	$Sn(OTf)_2$	**2**	C	CH_2Cl_2	78	82[e)]
17	Bu^i	$Sn(OTf)_2$	**2**	D	CH_2Cl_2	90	82[e)]
18	Bu^i	$Sn(OTf)_2$	**2**	E	CH_2Cl_2	86	80[e)]
19	Bu^i	$Sn(OTf)_2$	**2**	F	CH_2Cl_2	73	67[e)]
20	Bu^i	$Sn(OMs)_2$	**2**	B	CH_2Cl_2	63	2[d)]

a) The mixture of tin(II) compound, divalent tin, chiral diamine, and allylaluminum was run for 30 min at −78 °C, before benzaldehyde was added. (Entries 9—20). All reactions were carried out at −78 °C for 1 h. b) Tin(II) compound-chiral diamine-allylalminum-benzaldehyde A=1.0 : 1.0 : 1.0 : 0.7, B=1.3 : 1.3 : 1.0 : 0.7 C=2.0 : 2.0 : 1.0 : 0.7, D=1.6 : 1.6 : 1.0 : 0.7, E=1.1 : 1.1 : 1.0 : 0.7, F=0.8 : 0.8 : 1.0 : 0.7. c) Isolated yield. Yields are based on benzaldehyde. All the products have S-configuration. d) Based on $[\alpha]_D^{18}$ −48.7° (*c* 6.92, PhH) for (*S*)-1-phenyl-3-buten-1-ol.[6c)] e) Determined by ^{19}F NMR measurement of the ester from (*R*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride.



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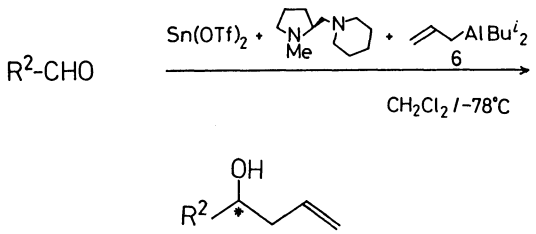
hyde at the same temperature, and the reaction mixture was stirred for an additional hour at −78 °C. Usual workup of the reaction mixture afforded 1-phenyl-3-buten-1-ol (**1**). The substituents of the tin(II) compound influenced remarkably the optical purity of the homoallylic alcohol **1** produced by the present allylation reaction (Entries 2—6). When tin(II) chloride or bromide was used, the enantioselectivity of the reaction was low, however, introduction of electron-withdrawing group such as trifluoromethanesulfonate as substituents of the tin(II) species increased the enantioselectivity of the reaction. Thus, when tin(II) triflate was used, good optical purities were attained, while the optical purity of the product dramatically decreased on use of tin(II) methanesulfonate instead of tin(II) triflate (Entries 20). It is assumed that as tin(II) triflate has electron-withdrawing group such as trifluoromethanesulfonate as substituents, that the tin(II) compound can strongly bind to the chiral diamine leading to effective enhancement of the enantioselectivity of the reaction.

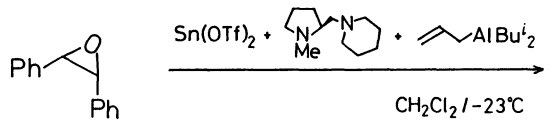
In order to find the most suitable solvent for the present allylation reaction, the influence of various solvents on the reaction was examined (Entries 6—8). These results indicate that CH_2Cl_2 is the preferred solvent and that using THF, a highly coordinating solvent, led to a sharp decrease in the optical purity of the product. This implies that the chelate structure existing in the transition state plays an important role in the enantioselectivity. It was also found that reverse addition of the reactants also affects the optical purity. That is, when allyldiethylaluminum was added to the mixture of tin(II) triflate, chiral diamine and benzaldehyde at −78 °C, the optical purity decreased dramatically from 42 to 6% ee. In addition, when benzaldehyde was added at −78 °C, after the mixture of tin(II) triflate, chiral diamine and allyldiethylaluminum was run for 30 min at −78 °C, optical purity increased from 42 to 52% ee. (Entry 9) Judging from these results, initial formation of the complex, chiral allylating agent, prepared from tin(II) triflate, chiral diamine and allylaluminum seems to be important for this asymmetric allylation. The effect of the *N*-substituents in the ligand diamines on the enantioselectivity in the present allylation reaction was also examined by using *N*-substituted diamines (Entries 10—13). Relatively high enantioselectivity was achieved when (*S*)-1-methyl-2-[(1-piperidinyl)methyl]pyrrolidine (**2**) was used as the ligand diamine. It was also found that the substituents of the allylaluminum had a

significant effect on the enantioselectivity of the product (Entries 13—15). When allyldiisobutylaluminum (**6**) having bulky substituents was employed as the allylaluminum, the enantioselectivity of the reaction increased from 61 to 84% ee. In contrast, the molar ratio of each reactant did not have any remarkable effect on the enantioselectivity of the reaction, however, the enantioselectivity of the reaction decreased from 80 to 67% ee, when the molar ratio of tin(II) triflate and diamine decreased from 1.1 to 0.8 (Entries 15—19). These results indicate that this chiral allylating agent consists of a 1 : 1 : 1 complex of tin(II) triflate, diamine and allylaluminum. Finally, the use of other allylic organometallics instead of allylaluminum was studied. When trisallyl borane,[10] allyllithium,[11] allylmagnesium bromide and allyltriphenyltin was used, asymmetric induction could not be observed indicating that the aluminum atom of allyla luminum plays an important role in the present reaction.



Having optimized the reaction conditions, the reaction with various aldehydes was examined and these results are summarized in Table 2. The allylation with other aldehydes proceeded smoothly to afford the corresponding homoallylic alcohols in high yield in any case. In the cases of aromatic aldehydes, fairly good optical purities were achieved. Electron-withdrawing groups or electron-donating groups in the aryl substituent did not have any remarkable effect either on the synthetic or on the optical yield. On the other hand, in the case of aliphatic aldehydes, satisfactory results could not be obtained, however, relatively good optical purities were attained when α,β-unsaturated aldehydes were employed.

Asymmetric Allylation of Epoxide with Chiral Allylating Agent. Highly selective transformations of enantiotopic groups in prochiral or meso compounds are well-known in enzymatic processes,[12] however, only a few enantioselective chemical approaches have been reported.[13] In order to study the asymmetric carbon-carbon bond forming reaction to meso compound, we examined the asymmetric reaction of the chiral allylating agent with a meso *cis*-epoxide. The allylation was carried out using *cis*-stilbene oxide (**7**) as a *cis*-epoxide. The research mixture of tin(II) triflate and chiral diamine **2** was cooled to 0 °C, and



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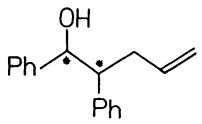

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allylaluminum **6** and *cis*-stilbene oxide (**7**) were added successivly at 0 °C. The mixture was stirred for 1 h at

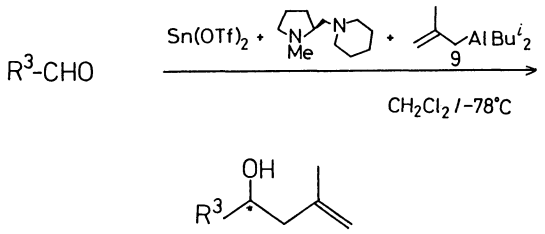
Table 2. Asymmetric Allylation of Aldehydes with Chiral Allylating Agent[a]

Entry No.	Aldehyde	Yield[b] %	$[\alpha]_D$ (c, solvent)	% ee (Configuration)
1	Benzaldehyde	91	$[\alpha]_D^{21}$—39.9° (2.48, PhH)	84[c] 82[d](S)[d]
2	4-Chlorobenzaldehyde	92	$[\alpha]_D^{23}$—28.4° (3.03, PhH)	84[e]
3	4-Nitrobenzaldehyde	65	$[\alpha]_D^{23}$—19.3° (2.14, PhH)	84[e]
4	4-Methylbenzaldehyde	85	$[\alpha]_D^{25}$—37.3° (2.00, PhH)	82[c]
5	4-Methoxybenzaldehyde	93	$[\alpha]_D^{23}$—65.8° (3.56, PhH)	80[c]
6	1-Naphthaldehyde	80	$[\alpha]_D^{24}$—77.5° (2.98, PhH)	80[c]
7	3-Phenyl-2-propenal	84	$[\alpha]_D^{19}$+9.29° (1.41, Et_2O)	64[e] (S)[f]
8	3-Phenylpropanal	86	$[\alpha]_D^{23}$+11.1° (3.14, $CHCl_3$)	53[c] (R)[g]
9	Cyclohexanecarbaldehyde	78	$[\alpha]_D^{25}$—1.78° (0.79, CH_2Cl_2)	56[c]
10	Nonanal	86	$[\alpha]_D^{23}$+5.22° (3.12, PhH)	40[c]

a) All reactions were carried out as described in Entry 15 in Table 1. b) Isolated yield. Yields are based on carbonyl compounds. c) The % ee was determined by ^{19}F NMR measurement of the ester from (*R*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride. d) Optically pure (*S*)-1-phenyl-3-buten-1-ol gives $[\alpha]_D^{18}$—48.7° (*c* 6.92, PhH).[6c] e) Determined by ^{19}F NMR measurement of the ester from (*R*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride in the presence of $Eu(fod)_3$. f) Optically active (*S*)-1-phenyl-1,5-hexadien-3-ol gives $[\alpha]_D^{20}$+3.60° (*c* 10.08, Et_2O).[6c] g) Optically active (*R*)-1-phenyl-5-hexen-3-ol gives $[\alpha]_D^{20}$+16.9° (*c* 1, $CHCl_3$).[6c]

the same temperature to gave 1,2-diphenyl-4-penten-1-ol (**8**) in 69% yield with optical purity of 40% based on NMR analysis of the corresponding MTPA ester. Examination of effect of temperature shows that lowering the temperature from 0 to −23 °C increased the enantioselectivity of the reaction from 40 to 50% ee. However, at the temperature lower than −23 °C, the reaction did not produce the corresponding bis homoallylic alcohol. Although the enantioselective deprotonation[13b,d] and ring-opening with thiols[13i] of a meso epoxide have been accomplished, the present result is, to our knowledge, the first example of an enantioselective allylation of a meso epoxide.

Asymmetric Methallylation of Aldehyde with Chiral Methallylating Agent. Next, we examined the asymmetric methallylation reaction with aldehyde based on the above mentioned consideration: Diisobutyl(2-methyl-2-propenyl)aluminum (diisobutylmethallylaluminum) (**9**) is readily prepared by treatment of diisobutylaluminum chloride with methallyl magnesium chloride at 0 °C in Et_2O, followed by exchange of solvent to CH_2Cl_2 in a similar procedure to that for allylaluminum. This solution of methallylaluminum **9** in CH_2Cl_2 was used for the reactions with aldehyde. The



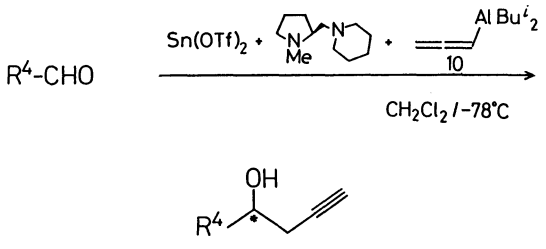
reactions were carried out according to a procedure similar to the previous asymmetric allylation and the results are summarized in Table 3. The reaction of aldehyde with chiral methallylating agent affords the corresponding methallylated product in good yields with high optical purities. The absolute configuration of the product which was obtained by the reaction with benzaldehyde was S-configuration as that of allylation. In the case of both aromatic and aliphatic aldehydes, relatively high optical purities were attained compared with those observed in the asymmetric allylation. Interestingly, in the case of nonanal, the enantioselectivity of the reaction increased from 40 to 73% ee.

Asymmetric Propargylation of Aldehyde with Chiral Propargylating Agent. Asymmetric propargylation is as useful as asymmetric allylation for asymmetric carbon-carbon bond forming reaction. The successful asymmetric propargylation of aldehydes with chiral allenylboronic ester has been reported by Yamamoto.[14] In this reaction, the chiral auxiliary is incorporated into the propargylating reagent. In order to explore the scope of the asymmetric carbon-carbon bond formation utilizing a chiral chelating agent, the asymmetric propargylation with aldehydes was studied. Asymmetric propargylation could be achieved by use of propargylaluminum instead of allylaluminum. The propargylaluminum derivative **10** was prepared as follows: To a solution of diisobutylaluminum chloride in hexane was added the Grignard reagent prepared from propargyl bromide and magnesium in Et_2O at 0 °C and the solvent was changed to CH_2Cl_2. In the first place, the reaction of benzaldehyde with the above solution of **10** afforded the desired homopropargylic alcohol and none of the allenic alcohol was obtained. The same results are reported by Eiter in the reaction of propargylaluminum derivative, derived from aluminum amalgam and propargyl bromide, with carbonyl compounds.[15] It is recognized that the propargylic organometallics are in equilibrium with allenic organometallic and that propargylic alcohols are obtained by the reaction of allenic organometallics with carbonyl compounds via a allylic rearrangement of the allenic organometallics.[16] These results indicate that allenic structure predominates in the above solution of propargylaluminum derivative. The reaction of the propargylating agent, prepared from **10**, tin(II) triflate, and chiral diamine, with aldehyde were carried out according to a procedure similar to that for the asymmetric allylation. We examined the effect of the *N*-substituents in the ligand diamines on the enantioselectivity by using some *N*-substituted diamines. When chiral diamine **2** was used, relatively high enantioselectivity was attained. The reaction with benzaldehyde under these condi-

Table 3. Asymmetric Methallylation of Aldehydes with Chiral Methyllylating Agent

Entry No.	Aldehyde	Yield[a] %	$[\alpha]_D$ (c, solvent)	% ee[b]
1	Benzaldehyde	80	$[\alpha]_D^{21}$−46.6° (1.97, PhH)	87[c]
2	4-Chlorobenzaldehyde	84	$[\alpha]_D^{21}$−40.4° (3.15, PhH)	88
3	3-Phenyl-2-propenal	85	$[\alpha]_D^{22}$−1.69° (2.43, Et_2O)	71
4	3-Phenylpropanal	85	$[\alpha]_D^{23}$+16.6° (2.66, $CHCl_3$)	67
5	Nonanal	70	$[\alpha]_D^{21}$+9.74° (2.71, PhH)	73

a) Isolated yield. Yields are based on aldehydes. b) The % ee was determined by ^{19}F NMR measurement of the ester from (*R*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride. c) S-Configuration. Based on Ref. 6a.



tions affords (*S*)-1-phenyl-3-butyn-1-ol in 60% ee. The reaction with other aldehydes also affords the corresponding homopropargylic alcohols in good yield with good optical purity as shown in Table 4. Interestingly, none of the allenic alcohols were obtained in any case as same as the reaction of **10** with aldehyde.

A highly enantioselective allylation of aldehydes has been accomplished by this new chiral allylating agent. The precise mechanism of the present allylation reaction that enables high enantioselectivity is not clear, however, the high enantioselectivity in the present reaction is assumed to be dependent on the following factors: The chiral allylating agent is generated from a 1 : 1 : 1 complex of chiral diamine **2**, tin(II) triflate and allylaluminum **6**. In this complex, **2** is coordinated to the tin(II) metal center, and in addition one of the oxygen atoms of tin(II) triflate is coordinated to the aluminum of **6** as shown in Fig. 1. Tin(II) triflate, **2** and **6** can form a rigid complex, because tin(II) triflate can strongly bind to the chiral diamine and aluminum has a strong affinity for oxygen. Thus, the chiral diamine **2** as chiral auxiliary and allylaluminum **6** as allylating reagent are brought into proximity by the chelation with tin(II) triflate. As a result, the direction of approach of the aldehyde to this complex is limited by the chiral diamine **2** and the isobutyl group, bulky substituents of the allylaluminum **6** in this complex

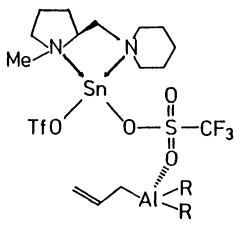


Fig. 1.

leading to high optical purities. In the case of the asymmetric methallylation, relatively high optical purities were attained compared with those of the asymmetric allylation. In this case, the direction of approach of the aldehyde to the complex is extremely restricted by **2** and the isobutyl and methallyl group of **9** leading to relatively high optical purities.

It is noted that treatment of tin(II) triflate, chiral diamine, and allylaluminum generates a new chiral allylating agent. This chiral agent is efficient for the enantioselective synthesis of homoallylic alcohols with satisfactory chemical and optical yields. The present procedure is the first example of the asymmetric allylation reaction with high optical purity induced by the chelation of a chiral auxiliary to active intermediate species. Furthermore, this newly introduced method is applicable to asymmetric methallylation and propargylation.

Experimental

IR spectra were recorded on a Hitachi 260-30 spectrometer. ^{1}H NMR spectra were recorded on a Hitachi R-24B (60 MHz) using TMS as an internal standard. ^{19}F NMR spectra were recorded on a Varian EM-390 (90 MHz) using hexafluorobenzene as an internal standard. Optical rotations were recorded on a JASCO DIP-181 automatic polarimeter using 1-dm thermostated microcell.

All reactions were carried out under an atmosphere of argon. CH_2Cl_2 was distilled successively from P_2O_5 and calcium hydride. Et_2O was freshly distilled from sodium metal using benzophenone ketyl as indicator. The (*R*)-3,3,3-trifluoro-2-methoxy-2-phenylpropionates (MTPA esters) were prepared according to Mosher's procedure[17] using the acid chloride derived from (*R*)-(+)-MTPA supplied from Aldrich (99+%).

Optical purity was determined by ^{19}F NMR of the MTPA esters of the alcohols or ^{19}F NMR of the MTPA esters in the presence of Eu(fod)$_3$.

Tin(II) Trifluoromethanesulfonate (Tin(II) Triflate). Tin(II) triflate was prepared from $SnCl_2$ and trifluoromethanesulfonic acid according to a procedure similar to that of Ref. 2. All handling of tin(II) triflate was carried out under argon atmosphere.

Preparation of Chiral Diamine. Chiral diamines were prepared from (*S*)-proline by a procedure similar to that of Ref **2**.

(*S*)-1-Methyl-2-[(1-piperidinyl)methyl]pyrrolidine: bp 116—

Table 4. Asymmetric Propargylation of Aldehydes with Chiral Propargylating Agent

Entry No.	Aldehyde	Yield[a] %	$[\alpha]_D$ (*c*, MeOH)	% ee[b]
1	Benzaldehyde	77	$[\alpha]_D^{21}$—6.93° (2.18)	60[c]
2	1-Naphthaldehyde	68	$[\alpha]_D^{28}$—29.7° (1.89)	52
3	3-Phenylpropanal	61	$[\alpha]_D^{25}$+21.4° (1.55)	54
4	3-Phenyl-2-propenal	45	$[\alpha]_D^{17}$+17.3° (1.65)	48

a) Isolated yield. Yields are based on aldehyde. b) The % ee was determined by ^{19}F NMR measurement of the ester from (*R*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetyl chloride. c) S-Configuration. Based on Ref. 14.

118 °C/20 mmHg (1 mmHg=133.322 Pa); IR (neat) 2935, 2770, 1450 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.28—1.88 (m, 10H), 1.88—2.50 (m, 8H), 2.4 (s, 3H), 2.92—3.15 (m, 1H); $[\alpha]_D^{21}$ −66.9° (*c* 0.32, EtOH).

Preparation of Allyldiisobutylaluminum. To a solution of diisobutylaluminum chloride (6.25 mmol) in 10 ml of hexane was added dropwise allylmagnesium bromide (6.25 mmol) in 10 ml of Et_2O at 0 °C under argon atmosphere. After warming to room temperature, the reaction mixture was stirred for 3 h at this temperature and evaporated. A minimum amount of CH_2Cl_2 was added to the residue and the mixture was evaporated in vacuo. The same operation was repeated again and finally 25.0 ml of CH_2Cl_2 was added. The resulting suspension was decanted and the supernatant used for the reaction.

Methallyldiisobutylaluminum was prepared from methallylmagnesium chloride and diisobutylaluminum chloride by an analogous procedure. Propargyldiisobutylaluminum derivative was prepared from propargylmagnesium bromide and diisobutylaluminum chloride by an analogous procedure.

Asymmetric Allylation of Aldehydes with Chiral Allylating Agent (Table 2). A typical reaction procedure is described for the reaction of benzaldehyde using (*S*)-1-methyl-2-[(1-piperidinyl)methyl]pyrrolidine (Entry 1); to a suspension of tin(II) triflate (224 mg, 0.54 mmol) and (*S*)-1-methyl-2-[(1-piperidinyl)methyl]pyrrolidine (97.9 mg, 0.54 mmol) in 4 ml of CH_2Cl_2 was added dropwise allyldiisobutylaluminum (2.1 ml of a stock solution in CH_2Cl_2, 0.42 mmol) at −78 °C under argon atmosphere. After the yellow solution was stirred for 30 min, benzaldehyde (29.5 mg, 0.28 mmol) in 2 ml of CH_2Cl_2 was added dropwise at −78 °C. The resulting mixture was stirred for 1 h at the same temperature, then quenched with sat. NH_4Cl aq and 1M HCl (1M=1 mol dm^{-3}). The organic layer was extracted with CH_2Cl_2 and dried over anhydrous Na_2SO_4. After concentration in vacuo the resulted oily substance was purified by preparative TLC (hexane-Et_2O=8:3) to yield 1-phenyl-3-buten-1-ol (37.2 mg, 91%). IR (neat) 3400, 1640, 1490, 1450 cm^{-1} ^1H NMR (CCl_4) δ=2.02 (s, 1H), 2.28 (t, *J*=6.6 Hz, 2H), 4.45 (t, *J*=6.6 Hz, 1H), 4.70—6.00 (m, 3H), 7.16 (s, 5H).

Other spectral data are presented: 1-(4-Chlorophenyl)-3-buten-1-ol (Entry 2). IR (neat) 3400, 1640, 1600, 1500 cm^{-1}; ^1H NMR (CCl_4) δ=2.02 (s, 1H), 2.26 (dd, *J*=6.2 Hz, 2H), 4.46 (t, *J*=6.2 Hz, 1H), 4.68—6.00 (m, 3H), 7.13 (s, 4H).

1-(4-Nitrophenyl)-3-buten-1-ol (Entry 3). IR (neat) 3400, 1640, 1600, 1520, 1350 cm^{-1}; ^1H NMR (CCl_4) δ=2.00 (br s, 1H), 2.40 (dd, *J*=6.2, 6.2 Hz, 2H), 4.71 (t, *J*=6.2 Hz, 1H), 4.85—6.10 (m, 3H), 7.38 (d, *J*=8.6 Hz, 2H), 8.05 (d, *J*=8.6 Hz, 2H).

1-(4-Methylphenyl)-3-buten-1-ol (Entry 4). IR (neat) 3400, 1640, 1520 cm^{-1}; ^1H NMR (CCl_4) δ=1.89 (s, 1H), 2.32 (s, 3H), 2.38 (dd, *J*=6.2, 6.2 Hz, 2H), 4.52 (t, *J*=6.2 Hz, 1H), 4.80—6.10 (m, 3H), 7.08 (s, 4H).

1-(2-Methoxyphenyl)-3-buten-1-ol (Entry 5). IR (neat) 3400, 1640, 1600, 1580, 1490, 1460 cm^{-1}; ^1H NMR (CCl_4) δ=2.02 (s, 1H), 2.20—2.55 (m, 2H), 3.80 (s, 3H), 4.86—6.05 (m, 3H), 6.60—7.40 (m, 4H).

1-(1-Naphthyl)-3-buten-1-ol (Entry 6). IR (neat) 3400, 1640, 1600, 1520 cm^{-1}; ^1H NMR (CCl_4) δ=2.12 (s, 1H), 2.35—2.75 (m, 2H), 4.84—6.25 (m, 4H), 7.15—8.10 (m, 7H).

1-Phenyl-1,5-hexadien-3-ol (Entry 7). IR (neat) 3350, 1640, 1600, 1490, 1450 cm^{-1}; ^1H NMR (CCl_4) δ=1.87 (s, 1H), 2.22 (dd, *J*=6.2, 6.2 Hz, 2H), 4.13 (dt, *J*=6.2, 6.2 Hz, 1H), 4.75—5.22 (m, 2H), 5.30—6.70 (m, 3H), 7.18 (s, 5H).

1-Phenyl-5-hexen-3-ol (Entry 8). IR (neat) 3400, 2920, 1640, 1600, 1500, 1460 cm^{-1}; ^1H NMR (CCl_4) δ=1.45 (s, 1H), 1.55—1.90 (m, 2H), 1.95—2.32 (m, 2H), 2.40—2.85 (m, 2H), 3.48 (tt, *J*=6.0, 6.0 Hz, 1H), 4.80—6.20 (m, 3H), 7.09 (s, 5H).

1-Cyclohexyl-3-buten-1-ol (Entry 9). IR (neat) 3400, 2930, 2860, 1640, 1450 cm^{-1}; ^1H NMR (CCl_4) δ=0.80—2.10 (m, 12H), 2.10—2.40 (m, 2H), 3.10—3.50 (m, 1H), 4.80—6.10 (m, 3H).

1-Dodecen-4-ol (Entry 10). IR (neat) 3350, 2920, 2850, 1640, 1460 cm^{-1}; ^1H NMR (CCl_4) δ=0.88 (t, *J*=5.0 Hz, 3H), 1.30 (br s, 15H), 1.95—2.30 (m, 2H), 3.25—3.70 (m, 1H), 4.80—6.10 (m, 3H).

Asymmetric Allylation of *cis*-Stilbene Oxide with Chiral Allylating Agent. To a suspension of tin(II) triflate (202 mg, 0.49 mmol) and (*S*)-1-methyl-2-[(1-piperidinyl)methyl]-pyrrolidine (88.5 mg, 0.49 mmol) in 4 ml of CH_2Cl_2 was added dropwise allyldiisobutylaluminum (1.9 ml of a stock solution in CH_2Cl_2, 0.37 mmol) at −23 °C under argon atmosphere. After the yellow solution was stirred for 5 min, *cis*-stilbene oxide (43.3 mg, 0.22 mmol) in 2 ml of CH_2Cl_2 was added dropwise at −23 °C. The resulting mixture was stirred for 1 h at the same temperature, then quenched with sat. NH_4Cl aq and 1M HCl. The organic layer was extracted with CH_2Cl_2 and dried over anhydrous Na_2SO_4. After evaporation of the solvent, the crude product was purified by (hexane-Et_2O=7 : 4) preparative TLC to afford 1,2-diphenyl-4-penten-1-ol (33.2 mg, 63%). IR (neat) 3400, 1640, 1600, 1500 cm^{-1}; ^1H NMR (CCl_4) δ=1.34 (s, 1H), 1.80—2.20 (m, 2H), 3.69 (d, *J*=8.0 Hz, 1H), 3.90—4.40 (m, 1H), 4.58—6.20 (m, 3H), 7.12 (s, 10H); $[\alpha]_D^{17}$ −7.24° (*c* 2.21, CH_2Cl_2).

The optical purity of the product was determined by conversion to the diastereoisomeric mixture of (*R*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetic acid esters. ^{19}F NMR analysis showed two clearly separated peaks with a ratio of 75 : 25.

Asymmetric Methallylation of Aldehydes with Chiral Methallylating Agent (Table 3). A typical reaction procedure is described for the reaction of benzaldehyde (Entry 1); to a suspension of tin(II) triflate (184 mg, 0.44 mol) and (*S*)-1-methyl-2-[(1-piperidinyl)methyl]pyrrolidine (80.4 mg, 0.44 mmol) in 4 ml of CH_2Cl_2 was added dropwise methallyldiisobutylaluminum (1.7 ml of a stock solution in CH_2Cl_2, 0.34 mmol) at −78 °C under argon atmosphere. After the yellow solution was stirred for 30 min, benzaldehyde (24.3 mg, 0.23 mmol) in 2 ml of CH_2Cl_2 was added dropwise at −78 °C. The resulting mixture was stirred for 1 h at the same temperature, then quenched with sat. NH_4Cl aq and 1M HCl. The organic layer was extracted with CH_2Cl_2 and dried over Na_2SO_4. After evaporation of the solvent, the crude product was purified by preparative TLC (hexane-Et_2O=7 : 3) to yield 1-phenyl-3-methyl-3-buten-1-ol (29.5 mg, 80%). IR (neat) 3400, 1650, 1500, 1450 cm^{-1}; ^1H NMR (CCl_4) δ=1.75 (s, 3H), 1.91 (s, 1H), 2.32 (d, *J*=7.0 Hz, 2H), 4.67 (t, *J*=7.0 Hz, 1H), 4.76 (br s, 2H), 7.19 (s, 5H).

Other spectral data are presented: 1-(4-Chlorophenyl)-3-methyl-3-buten-1-ol (Entry 2). IR (neat) 3400, 1650, 1500, 1450 cm^{-1}; ^1H NMR (CCl_4) δ=1.62 (s, 3H), 1.95 (s, 1H), 2.18 (d, *J*=7.0 Hz, 2H), 4.55 (t, *J*=7.0 Hz, 1H), 4.60—4.90 (m, 2H), 7.14 (s, 4H); Found: *m/z* 196.0629. Calcd for $C_{11}H_{13}OCl$: M, 196.0653.

1-Phenyl-5-methyl-5-hexen-3-ol (Entry 4). IR (neat) 3400, 2940, 1650, 1600, 1500, 1460 cm^{-1}; ^1H NMR (CCl_4) δ=1.30—1.90 (m, 6H), 2.10 (d, J=7.0 Hz, 2H), 2.50—3.00 (m, 2H), 3.62 (tt, J=7.0, 7.0 Hz,1H), 4.50—5.10 (m, 2H), 7.12 (s, 5H); Found: m/z 190.1397. Calcd for $C_{13}H_{18}O$: 190.1357.

1-Phenyl-5-methyl-1,5-hexadien-3-ol (Entry 3). IR (neat) 3400, 1650, 1600, 1500, 1450 cm^{-1}; ^1H NMR (CCl_4) δ=1.78 (s, 3H), 1.94 (s, 1H), 2.25 (d, J=7.0 Hz, 2H), 4.30 (dt, J=6.0, 6.0 Hz, 1H), 4.79 (br s, 2H), 5.8—6.8 (m, 2H), 7.22 (s, 5H).

2-Methyl-1-dodecen-4-ol (Entry 5). IR (neat) 3400, 2930, 1640, 1450 cm^{-1}; ^1H NMR (CCl_4) δ=0.88 (t, J=6.0 Hz, 3H), 1.30 (br s, 15H), 1.74 (s, 3H), 1.90—2.20 (m, 2H), 3.30—3.80 (m, 1H), 4.60—4.90 (m, 2H).

Asymmetric Propargylation of Aldehydes with Chiral Propargylating Agent (Table 4). A typical reaction procedure is described for the reaction of benzaldehyde (Entry 1); to a suspension of tin(II) triflate (208.5 mg, 0.50 mmol) and (*S*)-1-methyl-2-[(1-piperidinyl)methyl]pyrrolidine (91.2 mg, 0.50 mmol) in 4 ml of CH_2Cl_2 was added dropwise propargylaluminum derivative (2.0 ml of a stock solution in CH_2Cl_2, 0.39 mmol) at −78 °C under argon atmosphere. After the yellow solution was stirred for 30 min, benzaldehyde (30.2 mg, 0.29 mmol) in 2 ml of CH_2Cl_2 was added dropwise at −78 °C. The resulting mixture was stirred for 2 h at the same temperature, then quenched with sat. NH_4Cl aq and 1M HCl. The organic layer was extracted with CH_2Cl_2 and dried over Na_2SO_4. After concentration in vacuo the resulted oily substance was purified by preparative TLC (hexane-Et_2O=7 : 3) to yield 1-phenyl-3-butyn-1-ol (32.2 mg, 77%). IR (neat) 3400, 3300, 2100, 1500, 1460 cm^{-1}; ^1H NMR (CCl_4) δ=1.88 (t, J=2.5 Hz, 1H), 2.50 (dd, J=2.5, 6.6 Hz, 2H), 2.40 (s, 1H), 4.72 (t, J=6.6 Hz, 1H), 7.26 (s, 5H). Other spectral data are presented.

1-(1-Naphthyl)-3-butyn-1-ol (Entry 2). IR (neat) 3400, 3300, 2100, 1600, 1500 cm^{-1}; ^1H NMR (CCl_4) δ=1.90 (t, J=2.5 Hz, 1H), 2.40—2.95 (m, 3H), 5.10—5.55 (m, 1H), 7.05—8.10 (m, 7H); Found: m/z 196.0825. Calcd for $C_{14}H_{12}O$: M, 196.0887.

1-Phenyl-5-hexyn-3-ol (Entry 3). IR (neat) 3400, 3300, 2920, 2100, 1600, 1500, 1450 cm^{-1} ^1H NMR (CCl_4) δ=1.50—2.00 (m, 3H), 2.27 (dd, J=2.5, 6.0 Hz, 2H), 2.40—3.00 (m, 3H), 3.30—3.90 (m, 1H), 7.08 (s, 5H); Found: m/z 174.1039. Calcd for $C_{12}H_{14}O$: M, 174.1043.

1-Phenyl-1-hexen-5-yn-3-ol (Entry 4). IR (neat) 3400, 3300, 2100, 1650, 1490, 1450 cm^{-1}; ^1H NMR (CCl_4) 1.92 (t, J=2.5 Hz, 1H), 2.43 (dd, J=2.5, 6.0 Hz, 2H), 2.72 (s,1H), 4.05—4.50 (m, 1H), 5.75—6.70 (m, 2H), 7.15 (s, 5H); Found; m/z 172.0934. Calcd for $C_{12}H_{12}O$: M, 172.0887.

References

1) J. D. Morrison, "Asymmetric Synthesis;" ed by Academic Press, New York (1983), Vol. 1—4.

2) N. Iwasawa and T. Mukaiyama, *Chem. Lett.*, **1982**, 1441; **1983**, 297; R. W. Stevens and T. Mukaiyama, *ibid.*, **1983**, 1799; T. Mukaiyama and N. Iwasawa, *ibid.*, **1984**, 753; T. Mukaiyama, N. Iwasawa, R. W. Stevens, and T. Haga, *Tetrahedron*, **40**, 1381 (1984).

3) J. Ichikawa, M. Asami, and T. Mukaiyama, *Chem. Lett.*, **1984**, 949.

4) T. Oriyama and T. Mukaiyama, *Chem. Lett.*, **1984**, 2071; T. Mukaiyama, K. Tomimori, and T. Oriyama, *ibid.*, **1985**, 813, 1359.

5) S. Masamune, G. S. Bates, and J. W. Corcoran, *Angew. Chem., Int. Ed. Engl.*, **16**, 585 (1977).

6) a) B: T. Herold and R. W. Hoffmann, *Angew. Chem., Int. Ed. Engl.*, **17**, 768 (1978); R. W. Hoffmann and T. Herold, *Chem. Ber.*, **114**, 375 (1981); T. Herold, U. Schrott, and R. W. Hoffmann, *ibid.*, **114**, 359 (1981); M. M. Midland and S. B. Preston, *J. Am. Chem. Soc.*, **104**, 2330 (1982); H. C. Brown and P. K. Jadhar, *J. Am. Chem. Soc.*, **105**, 2092 (1983); H. C. Brown, P. K. Jadhar, and P. T. Perumal, *Tetrahedron Lett.*, **25**, 5111 (1984); H. C. Brown and P. K. Jadhar, *ibid.*, **25**, 1215 (1984); P. K. Jadhav, K. S. Bhat, P. T. Perumal, and H. C. Brown, *J. Org. Chem.*, **51**, 432 (1986); H. C. Brown and K. S. Bhat, *J. Am. Chem. Soc.*, **108**, 293, 5919 (1986); W. R. Roush and R. L. Halterman, *J. Am. Chem. Soc.*, **108**, 294 (1986). b) Si: T. Hayashi, M. Konishi, and M. Kumada, *J. Am. Chem. Soc.*, **104**, 4962; 4963 (1982); T. Hayashi, M. Konishi, and M. Kumada, *J. Org. Chem.*, **48**, 281 (1983); T. Hayashi, K. Kabeta, T. Yamamoto, K. Tamao, and M. Kumada, *Tetrahedron Lett.*, **24**, 5661 (1983); S. J. Hathaway and L. A. Paquette, *J. Org. Chem.*, **48**, 3351 (1983); L. Coppi, A. Mordini, and M. Taddei, *Tetrahedron Lett.*, **28**, 969 (1987). c) Sn: J. Otera, Y. Kawasaki, H. Mizuno, and Y. Shimizu, *Chem. Lett.*, **1983**, 1529; J. Otera, Y. Yoshinaga, T. Yamaji, T. Yoshioka, and Y. Kawasaki, *Organometallics*, **4**, 1213 (1986); G. P. Boldrini, E. Tagliavini, C. Trombini, and A. Umani-Ronchi, *J. Chem. Soc., Chem. Commun.*, **1986**, 685. d) Cr: B. Cazes, C. Verniere, and J. Gore, *J. Synth. Commun.*, **13**, 73 (1983).

7) a) I. Ojima, Y. Miyazawa, and K. Kumagai, *J. Chem. Soc., Chem. Commun.*, **1976**, 927; K. Soai and M. Ishizaki, *ibid.*, **1984**, 1016; *idem*, *J. Org. Chem.*, **51**, 3290 (1986); K. Soai, M. Ishizaki, and S. Yokoyama, *Chem. Lett.*, **1987**, 341. b) J. M. McNamara and Y. Kishi, *J. Am. Chem. Soc.*, **104**, 7371 (1982); P. A. Bartlett, W. S. Johnson, and J. D. Elliott, *ibid.*, **105**, 2088 (1983); S. H. Mashraqui, and R. M. Kellogg, *J. Org. Chem.*, **49**, 2513 (1984); R. Imwinkelried and D. Seebach, *Angew. Chem., Int. Ed. Engl.*, **24**, 765 (1985); T. Mukaiyama, M. Ohshima, and N. Miyoshi, *Chem. Lett.*, **1987**, 1121.

8) T. Mukaiyama, N. Minowa, T. Oriyama, and K. Narasaka, *Chem. Lett.*, **1986**, 97.

9) H. Lehmkuhl and D. Reinehr, *J. Organomet. Chem.*, **23**, C25 (1970).

10) A. Stefani and P. Pino, *Helv. Chim. Acta*, **55**, 1110 (1970).

11) D. Seyferth and M. A. Weiner, *J. Org. Chem.*, **26**, 4797 (1961).

12) For example: J. B. Jones, *Ciba Found. Symp.*, **111**, 3 (1985); Y. F. Wang, C. S. Chen, G. Girdaukas, and D. J. Sih, *ibid.*, **111**, 128 (1985); M. Ohno, *ibid.*, **111**, 171 (1985).

13) a) N. Cohen, *Acc. Chem. Res.*, **9**, 412 (1976); b) J. K. Whitsell and S. W. Felman, *J. Org. Chem.*, **45**, 755 (1980); c) K. Osakada, M. Obana, T. Ikariya, M. Saburi, and S. Yoshikawa, *Tetrahedron Lett.*, **22**, 4297 (1981); d) M. Asami, *Chem. Lett.*, **1984**, 829; e) J. Ichikawa, M. Asami, and T. Mukaiyama, *ibid.*, **1984**, 949; f) S. Hanessian, D. Delorme, S.Beaudoin, and Y. Leblanc, *J. Am. Chem. Soc.*, **106**, 5754 (1984); g) N. S. Simpkins, *J. Chem. Soc., Chem. Commun.*, **1986**, 88; h) R. Shirai, M. Tanaka, and K. Koga, *J. Am. Chem. Soc.*, **108**, 543 (1986); i) H. Yamashita and T. Mukaiyama, *Chem. Lett.*, **1985**, 1643.

14) R. Haruta, M. Ishiguro, N. Ikeda, and H. Yamamoto,

J. Am. Chem. Soc., **104**, 7667 (1982); N. Ikeda, I. Arai, and H. Yamamoto, *ibid.*, **108**, 483 (1986).

15) K. Eiter and H. Oediger, *Justus Liebigs Ann. Chem.*, **682**, 62 (1965); R. G. Daniels and L. A. Paquette, *Tetrahedron Lett.*,**22**, 1579 (1981).

16) J. L. Moreau "The Chemistry of Ketenes, Allenes, and Related Compounds," ed by S. Patai, Wiley, New York (1980).

17) J. A. Dale, D. L. Dull, and H. S. Mosher, *J. Org. Chem.*, **34**, 2543 (1969).