Available online at www.sciencedirect.com
SCIENCE DIRECT
Journal of Organometallic Chemistry 691 (2006) 1515–1519
Journal of Organometallic Chemistry
www.elsevier.com/locate/jorganchem

Note

Enantioselective catalytic allylation of arylmethylketones using tetraallyltin and tin(IV) chloride mixtures

Oscar Prieto, Simon Woodward *

School of Chemistry, The University of Nottingham, University Park, Nottingham NG7 2 RD, United Kingdom

Received 9 November 2005; accepted 9 November 2005
Available online 19 December 2005

Abstract

Reaction of $SnCl_4$ with $Sn(CH_2CH{=}CH_2)_4$ in the presence of water and monothiobinaphthol [2,2′-$C_{20}H_{12}$(OH)(SH)] allows the formation of a selective catalyst for the allylation of ketones (up to 94% e.e.).

Keywords: Tin; Asymmetric catalysis; Ketones; Allylation; Autocatalysis

1. Introduction

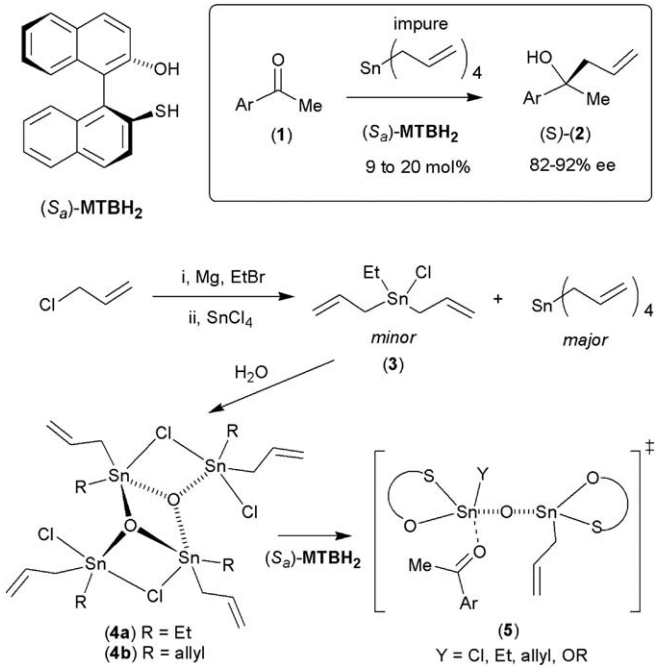
In 2002 we identified an unusual asymmetric reaction where, in the presence of catalytic amounts of the chiral ligand $MTBH_2$ samples of tetraallyltin of 98% chemical purity ketones were allylated up to nine times more selectively than with completely pure $Sn(CH_2CH{=}CH_2)_4$ (>99% purity gives <35% ee for PhC(O)Me) (Scheme 1) [1]. Subsequent careful work revealed the selective catalyst is formed from trace amounts of $EtSnCl(CH_2CH{=}CH_2)_2$ (**3**) derived from incomplete reaction of the $SnCl_4$ and the presence of EtBr (used for Grignard preparation) [2]. Compound (**3**) undergoes facile allyl hydrolysis with trace water to provide the crystallographically characterized bis(diallyldiethyldichlorodistanoxane) (**4a**). Reaction of (**4a**) with (S_a)-**1** led to a very selective catalyst which we propose operates via the working model (**5**) (Scheme 1). Alternative proposals via mononuclear species, such as (MTB)Sn(allyl)L species are possible but, in our hands, control reactions with such species are inactive or unselective. Our system is unique, not only for its complex reactivity, but because it is the only tin-based catalyst showing high enantioselectivity in this process, all other work concentration on titanium-based catalysts [3,4]. Unfortunately, preparation of pre-catalyst (**4a**) requires four synthetic steps. We wondered if we could attain similar reactivity based on in situ formation of (**4b**) improving the utility of this approach.

2. Results and discussion

Encouraged by the work of Baba, who added $SnCl_2$ to modify the reactivity of $Bu_3Sn(CH_2CH{=}CHPh)$ [5], we reasoned that addition of small amounts $SnCl_4$ to pure (>99%) commercially available tetraallyltin should result in the formation of (**4b**) through the intermediacy of $ClSn(CH_2CH{=}CH_2)_3$. From our previous studies, we knew that active catalysts are formed even if only trace amounts of water are present in such mixtures, however, the issue of stereoselectivity from such species was unknown. Therefore, tetraallyltin (1.07 equiv. based on ketone used), traces of water (0.41 equiv.) and chiral ligand (S_a)-$MTBH_2$ (20 mol%) were equilibrated with 1–3 mol% $SnCl_4$ (based on ketone used) in toluene at 50 °C to form active catalysts. Neat PhC(O)Me (100 mol%) was added to these solutions at room temperature and the dependence of product e.e. versus yield by GC over 16 h. With 2–3 mol% of the $SnCl_4$ promoter selective catalysts were formed but at 1 mol% the insufficient chiral catalyst was produced to compete with racemic background autocatalysis from the $Sn(allyl)_n[OC\text{-}Me(Ph)(allyl)]_{4-n}$ (n = 2–3) kinetic products [2].

* Corresponding author.
E-mail address: simon.woodward@nottingham.ac.uk (S. Woodward).

0022-328X/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.jorganchem.2005.11.017



Scheme 1.

The conversion dependent enantioselectivity of Fig. 1 suggested that formation of the selective catalyst is slow and therefore the presence of additional additives to further improve the process was sought (Table 1). As isopropanol had proved a valuable additive in Walsh's titanium-based chemistry [4] it was tried here but produced no significant improvement in the rate or selectivity in either the presence or absence of water (runs 2–4). Conversely, phenol promoted a dramatic increase in the reaction rate but at the loss of any significant stereoselection (run 6). We hypothesized that this might be to its exchange into the selective transition state (**5**) as phenoxide (Y = OPh). This hypothesis is supported by use of (−)-menthol which leads to a significant improvement in the stereoselectivity (run 7) at low substrate conversion suggesting it is incorporated as an *O*-menthyl group in (**5**). Unfortunately, the falling e.e. with increased conversion (run 8) strongly suggests the menthyl is lost from the catalyst the exchange with $(allkyl)_3SnOCMePh(allyl)$ product. The need for water in the system was confirmed as alternative catalyst

Table 1
Influence of different additives on $Sn(CH_2CH{=}CH_2)_4/SnCl_4/(S_a)$-$MTBH_2$ promoted acetophenone (**1** Ar = Ph) allylation[a]

Entry	Additive	Time/h	Product (S_a)-**2** (Ar = Ph)	
			Yield/%[b]	e.e./%[b,c]
1	None[a]	4	75	86
2	Pr^iOH[d,e]	2	51	72
3	Pr^iOH[d,e]	17	90	50
4	Pr^iOH[d,f]	17	75	18
5	PhOH[d,e]	2	>95	8
6	PhOH[f]	2	60	12
7	(−)-Menthol[g]	2	63	80
8	(−)-Menthol[g]	17	90	47
9	$(Bu^tO)_4Sn$[d,e]	17	70	26
10	$ClSiMe_3$[d,e]	71	>95	2
11	MS 4 Å[e]	17	90	40
12	Tetraallylsilane[g,h]	36	28	68
13	$(OEt)_3Si(allyl)$[g]	18	10	0
14	$Cl_3Si(allyl)$[g]	18	0	–

[a] Reagent mixture: $Sn(CH_2CH{=}CH_2)_4/SnCl_4/H_2O/(S_a)$-$MTBH_2$/PhC(O)Me 1.07:0.03:0.41:0.20:1.00 equiv. The e.e. value maximized at 86% (75% yield **2** at 6 h) but was 78% at the maximum conversion attained (95%).
[b] Determined by GLC, using undecane as internal standard. using a γ-CD column (see Section 4).
[c] Absolute configuration: (*S*)-**2**.
[d] 1 equiv. was used (w.r.t. **1**).
[e] Without water.
[f] Water was added (0.41 equiv. w.r.t. **1**).
[g] 5 mol% of tetraallyltin w.r.t. **1**; 20 mol% (S_a)-$MTBH_2/Sn(CH_2CH{=}CH_2)_4$.
[h] Reaction run using 5 mol% tetraallyltin.

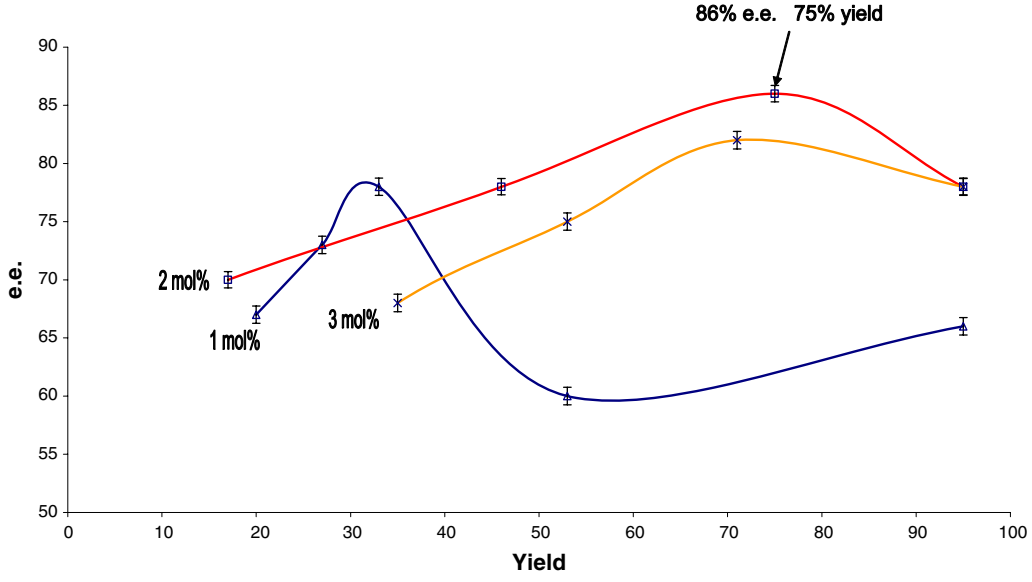


Fig. 1. Influence of $SnCl_4$ on $MTBH_2$-catalysed asymmetric allylation of acetophenone.

Table 2
Allylation of (**1**) using $Sn(CH_2CH{=}CH_2)_4/SnCl_4/(S_a)$-$MTBH_2$[a]

Entry	Ar	Time/h	Product (S_a)-**2** (Ar = Ph)	
			Yield/%[b]	e.e./%[b,c]
1	Ph	4	75	86
2	4-MeC_6H_4	3	47	66
3	(*E*)-PhCH=CH	3	53	55[d]
4	4-ClC_6H_4	3	70	81
5	4-BrC_6H_4	3	68	76
6	4-$NO_2C_6H_4$	3	85	94
7	4-(MeO)C_6H_4	3	<2	–
8	2-$C_{10}H_8$	3	45	80
9	Propiophenone	3	8	3
10	(*S*)-(−)-2-(3-bromophenyl)-pent-4-en-2-ol		70	76

[a] Reagent mixture: $Sn(CH_2CH{=}CH_2)_4/SnCl_4/H_2O/(S_a)$-$MTBH_2$/Ph-C(O)Me 1.07:0.03:0.41:0.20:1.00 equiv. The e.e. value maximized at 86% (75% yield **2** at 4 h) but was 78% at the maximum conversion attained (95%).
[b] Determined by GLC, using undecane as internal standard. using a γ-CD column (see Section 4).
[c] Absolute configuration (*S*).
[d] Absolute configuration not determined.

preparations using dehydrating agents all led to poor selectivities (runs 9–11). Finally, the possibility of using allylsilane as the terminal allyl source was investigated but rapid transmetallation to tin could not be attained (runs 12) and the reactions performed poorly in its absence (runs 13–14).

The optimal reaction procedure was applied to a range of arylmethyl ketones to define the scope and utility of the new process (Table 2). Optimal enantioselectivities were attained after 3–4 h in all cases. Running the reactions for longer periods resulted in lower e.e. values due to competion from background reactions. Best results were attained with an electron deficient ketone (run 6). Electron rich 4-(MeO)C_6H_4C(O)Me was inactive in this chemistry.

3. Conclusions

The possibility of using a simple achiral additive to strongly promote the stereoseletivity observed in tin-based asymmetric ketone allylation has been demonstrated. Dramatically improved e.e. values are attained without the need to prepare all the individual components of the mixtures of organotin species required for this chemistry. The presence of background racemic allylation, promoted by the kinetic product of the reaction dictates that the ligand accelerated catalysis brought about by the chiral ligand has to be great. A search is continuing to identify a ligand with superior properties to $MTBH_2$ as in this case a technically very simple process would be attained.

4. Experimental

4.1. General

Proton spectra were recorded on Bruker (AM 400) spectrometer at ambient temperature using tetramethylsilane as standard; *J* values are given in Hz. analysis by GC was performed on a Varian 3380 gas chromatograph. Analysis by HPLC was performed using a Hewlett-Packard 1100LC machine. Toluene solutions of $SnCl_4$ solutions were freshly prepared using commercial $SnCl_4$ (>98%) and toluene distilled from sodium wire. The allylated products were identified by comparison with authentic samples [2].

4.2. Representative catalytic allylation for acetophenone, (*S*)-(−)-2-phenyl-pent-4-en-2-ol

Solid (S_a)-(+)-$MTBH_2$ (24.0 mg, 0.08 mmol) in a Schlenk tube was treated with H_2O (3 μl, 0.16 mmol) and commercial available tetraallyltin (103 μl, 0.431 mmol) followed by the addition of a 2 or 3% $SnCl_4$ solution in toluene (8.8 or 13.2 μmol; 1.0 or 1.5 ml) under an atmosphere of argon. The resulting mixture was stirred at ambient temperature for 5 min then heated at 52 °C for 2 h. The mixture was allowed to cool to room temperature then acetophenone (47 μl, 0.4 mmol) was and undecane (10 μl) were added. The mixture was stirred up to 16 h. Every sample taken from the reaction mixture was concentrated and the residue chromatographed on silica (hexane then Et_2O). Yield was determined by GC up to 90%, e.e. up to 86%. ^1H NMR ($CDCl_3$, 400 MHz): δ 1.57 (s, 3H), 2.12 (s, 1H), 2.53 (dd, $J = 13.7$ and 8.3 Hz, plus unresolved couplings, 1H), 2.72 (ddt, $J = 13.7$, 6.4 and 1.1 Hz, 1H), 5.12–5.14 (m, 1H), 5.15–5.18 (m, 1H), 5.64 (dddd, $J = 14.7$, 10.2, 8.3 and 6.4 Hz, 1H), 7.26 (tt, $J = 7.3$ and 1.3 Hz 1H), 7.34–7.38 (m, 2H), 7.44–7.47 (m, 2H). These data were concordant with published values [2]. The enantiomeric excesses were determined by GC (6-Me-2,3-pe-γ-CD, 100 °C isothermal). Retention times 20.1. (*R*), 21.4 (*S*).

4.3. (*S*)-(−)-2-(4-bromophenyl)-pent-en-2-ol

Prepared by the allylation of 4-bromoacetophenone. Yield (after 3 h) 68% (76% e.e.); ^1H NMR ($CDCl_3$, 400 MHz): δ 1.53 (s, 3H), 2.12 (s, 1H), 2.49 (ddt, $J = 13.7$, 8.2 and 0.8 Hz, 1H), 2.64 (ddt, $J = 13.7$, 6.6 and 1.0 Hz, 1H), 5.10–5.13 (m, 1H), 5.15–5.18 (m, 1H), 5.60 (dddd, $J = 14.7$, 9.7, 8.2 and 6.6 Hz, 1H), 7.31 (dd, $J = 8.7$ and 2.0 Hz 2H), 7.46 (dd, $J = 8.7$ and 2.0 Hz, 2H). These data were concordant with published values [2]. The enantiomeric excesses were determined by GC (6-Me-2,3-pe-γ-CD, 90 °C initial, 4 deg min^{-1} to 125 °C). Retention times 42.0 (*R*), 43.1 (*S*).

4.4. (*S*)-(−)-(4-tolyl)-pent-4-en-2-ol

Prepared by the allylation of 4-methylacetophenone. Yield (after 3 h) 47% (66% e.e.); ^1H NMR ($CDCl_3$, 400 MHz): δ 1.55 (s, 3H), 2.04 (s, 1H), 2.36 (s, 3H), 2.50 (dd, $J = 13.7$ and 8.2 Hz, plus unresolved couplings, 1H), 2.69 (dd, $J = 13.7$ and 6.4 Hz, plus unresolved couplings,

1H) 5.11–5.13 (m, 1H), 5.14–5.17 (m, 1H), 5.64 (dddd, $J = 14.7$, 10.1, 8.2 and 6.4 Hz, 1H), 7.17 (d, $J = 8.2$ Hz, 2H), 7.34 (d, $J = 8.2$ Hz, 2H). These data were concordant with published values [2]. The enantiomeric excesses were determined by GC (6-Me-2,3-pe-γ-CD, 90 °C initial for 5 min, 3 deg min^{-1} to 110 °C). Retention times 26.2 (*R*), 27.2 (*S*).

4.5. 3-Methyl-1-phenyl-hexa-1,5-dien-3-ol

Prepared by the allylation of benzylidene acetone. Yield (after 3 h) 53% (55% e.e.); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.38 (s, 3H), 1.81 (s, 1H), 2.36 (ddt, $J = 13.6$, 8.1 and 0.8, 3H), 2.44 (ddt, $J = 13.6$, 6.7 and 1.1 Hz, 1H), 5.13–5.16 (m, 1H) 5.17–5.18 (m, 1H), 5.84 (dddd, $J = 16.4$, 10.8, 8.1 and 6.7, 1H), 6.29 (d, $J = 16.1$ Hz, 1H), 6.59 (d, $J = 16.1$ Hz, 1H), 7.22 (tt, $J = 7.3$ and 1.4 Hz, 1H), 7.28–7.33 (m, 2H), 7.36–7.39 (m, 2H). These data were concordant with published values [2]. The enantiomeric excesses were determined by GC (2,6-Me-3-pe-γ-CD, 70 °C initial for 25 min, 1 deg min^{-1} to 120 °C). Retention times 110.3, 113.2.

4.6. (S)-(−)-2-(4-chlorophenyl)-pent-4-en-2-ol

Prepared by the allylation of 4-chloroacetophenone. Yield (after 3 h) 70% (81% e.e.); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.54 (s, 3H), 2.05 (s, 1H), 2.49 (ddt, $J = 13.7$, 8.3 and 0.8 Hz, 1H), 2.65 (ddt, $J = 13.7$, 6.5 and 1.1 Hz, 1H), 5.10–5.14 (m, 1H), 5.15–5.18 (m, 1H), 5.60 (dddd, $J = 14.8$, 9.6, 8.3 and 6.6 Hz, 1H), 7.31 (d, $J = 8.8$ Hz, 2H), 7.38 (d, $J = 8.8$ Hz, 2H). These data were concordant with published values [2]. The enantiomeric excesses were determined by GC (6-Me-2,3-pe-γ-CD, 90 °C initial, 3 deg min^{-1} to 120 °C). Retention times 32.9 (*R*), 34.2 (*S*).

4.7. 3-Phenyl-hex-5-en-3-ol

Prepared by the allylation of propiophenone. Yield (after 3 h) 8% (3% e.e.); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 0.78 (t, $J = 7.4$ Hz, 3H), 1.80–1.91 (m, 2H), 2.04 (s, 1H), 2.51 (ddt, $J = 13.8$, 8.6 and 0.8 Hz, 1H), 2.74 (ddt, $J = 13.8$, 6.1, 1.4 Hz, 1H), 5.09–5.17 (m, 2H), 5.59 (dddd, $J = 14.8$, 10.1, 8.6, and 6.1 Hz, 1H), 7.24 (tt, $J = 7.2$ and 1.4 Hz, 1H), 7.32–7.37 (m, 2H), 7.39–7.42 (m, 2H). These data were concordant with published values [2]. The enantiomeric excesses were determined by GC (6-Me-2,3-pe-γ-CD, 90 °C initial, 2 deg min^{-1} to 100 °C). Retention times 27.7, 28.6.

4.8. (S)-(−)-2-(3-bromophenyl)-pent-4-en-2-ol

Prepared by the allylation of 3-bromoacetophenone. Yield (after 3 h) 70% (73% e.e.); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.54 (s, 3H), 2.02 (s, 1H), 2.50 (ddt, $J = 13.8$, 8.1 and 0.9 Hz, 1H), 2.65 (ddt, $J = 13.8$, 6.6 and 1.0 Hz, 1H), 5.10–5.15 (m, 1H), 5.15–5.16 (m, 1H), 5.64 (dddd, $J = 15.8$, 11.4, 8.1 and 6.6 Hz, 1H), 7.21 (t, $J = 7.9$ Hz, 1H), 7.36 (dd, $J = 7.9$, 1.9 and 1.0 Hz, 1H), overlapped by 7.37 (ddd, $J = 7.9$, 1.9 and 1.1 Hz, 1H), 7.63 (t, $J = 1.9$ Hz, 1H) These data were concordant with published values [2]. The enantiomeric excesses were determined by GC (Cyclodex-B, 120 °C isothermal). Retention times 130.1 (*S*), 135.6 (*R*).

4.9. (S)-(−)-2-(2-naphthyl)-pent-4-en-2-ol

Prepared by the allylation of 2-acetonaphthone. Yield (after 3 h) 45% (80% e.e.); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.66 (s, 3H), 2.23 (s, 1H), 2.61 (dd, $J = 13.8$, 8.4 Hz, plus unresolved couplings 1H), 2.82 (dd, $J = 13.8$, 6.4 Hz, plus unresolved couplings 1H), 5.14 (d, $J = 10.1$ Hz, plus unresolved couplings, 1H), 5.18 (d, $J = 14.7$ Hz, pus unresolved couplings, 1H), 5.64 (dddd, $J = 14.7$, 10.1, 8.4 and 6.4 Hz, 1H), 7.45–7.52 (m, 2H), 7.56 (dd, $J = 8.6$ and 1.9 Hz, 1H), 7.82–7.88 (m, 3H), 7.94 (d, $J = 1.7$ Hz, plus unresolved long range couplings 1H). These data were concordant with published values [2]. The enantiomeric excesses were determined by Diacel HPLC (OD column, 100:0–98:2 hexane:IPA over 35 min; flow rate 0.5 ml min^{-1}). Retention times 53.4 (*S*), 65.2 (*R*).

4.10. (S)-(−)-2-(4-nitrophenyl)-pent-en-2-ol

Prepared by the allylation of 4-nitroacetophenone. Yield (after 3 h) 85% (94% e.e.); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.58 (s, 3H), 2.22 (s, 1H), 2.54 (dd, $J = 13.8$ and 8.1 Hz, plus unresolved couplings, 1H), 2.68 (dd, $J = 13.8$ and 6.6 Hz, plus unresolved couplings 1H), 5.13–5.16 (m, 1H), 5.17–5.18 (m, 1H), 5.59 (dddd, $J = 16.3$, 10.8, 8.1 and 6.6 Hz, 1H), 7.62 (dd, $J = 9.0$ and 2.0 Hz, 2H), 8.19 (dd, $J = 9.0$ and 2.0 Hz, 2H). These data were concordant with published values [2]. The enantiomeric excesses were determined by Diacel HPLC (AD column, 95:5 hexane:IPA; flow rate 0.5 ml min^{-1}). Retention times 15.9 (*S*), 25.2 (*R*).

4.11. 2-(4-Methoxyphenyl)-pent-4-en-2-ol

Prepared by the allylation of 4-methoxyacetophenone. Yield (after 3 h) <2% (e.e. no determined); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.53 (s, 3H), 1.99 (s, 1H), 2.48 (dd, $J = 13.7$ and 8.1 Hz, plus unresolved couplings 1H), 2.66 (dd, $J = 13.7$ and 6.6 Hz, plus unresolved couplings 1H), 3.81 (s, 3H) 5.10 (apparent s, 1H), 5.14 (m, 1H), 5.63 (dddd, $J = 14.7$, 10.4, 8.1 and 6.6 Hz, 1H), 6.87 (dd, $J = 8.8$ and 2.1 Hz, 2H), 7.36 (dd, $J = 8.8$ and 2.1 Hz, 2H). These data were concordant with published values [2].

Acknowledgements

We thank EPSRC for an Award (GR/R69051/01) and The European Science Foundation for support through

the COST-D24 Programme. We thank a referee for pointing out the possibility of catalysis by (MTB)Sn(allyl)R species.

References

[1] A. Cunningham, S. Woodward, Synlett (2002) 43–44.
[2] A. Cunningham, V. Mokal-Parekh, C. Wilson, S. Woodward, Org. Biol. Chem. (2004) 728–741.
[3] S. Kii, K. Maruoka, Chirality 15 (2003) 68–70;
H. Hanawa, S. Kii, K. Maruoka, Adv. Synth. Catal. 343 (2001) 57–60.
[4] J.G. Kim, K.M. Waltz, I.F. Garcia, D. Kwiatkowski, P.J. Walsh, J. Am. Chem. Soc. 126 (2004) 12580–12585.
[5] M. Yasuda, K. Hirata, M. Nishino, A. Yamamoto, A. Baba, J. Am. Chem. Soc. 124 (2002) 13442–13447.