Enantioselectivity of the Transfer of Hydrogen Atoms to Acyclic Prochiral Carbon-Centred Radicals Using Chiral Tin Hydrides☆

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Racemic α-bromo esters **2** have been reduced via prochiral radicals **5** with low to moderate enantioselectivities using chiral tin hydrides **1** with a stereogenic tin atom containing chiral 2-[(1-dimethylaminoalkyl)phenyl] ligands. The tin hydrides **1** were mixtures of diastereomers. It could be shown that the minor diastereomer of tin hydrides **1a** and **1b** reacts with good enantioselectivity whereas the major diastereomer reacts almost unselectively. The observed enantioselectivities are also strongly influenced by steric effects of the substituents attached to the radical centre.

Introduction

The stereoselectivity of intermolecular reactions of acyclic alkyl radicals has been a subject of considerable interest[1]. Little is known about the enantioselectivity of the free-radical transfer of hydrogen atoms. The enantioselective abstraction of hydrogen atoms from chiral racemic carboxylates by chiral amine-boryl radicals giving rise to kinetic resolution was described by Roberts et al.[2]. We have recently reported on the first examples of the enantioselective transfer of hydrogen atoms from chiral tin hydrides to prochiral α-ester radicals[3][4]. Quite recently, the first results of the enantioselective hydrogen transfer using tin hydrides containing a C_2-symmetric binaphthyl moiety have been reported independently by us[5] and others[6]. We have now investigated the enantioselectivity of the free-radical reduction of some α-bromo esters using chiral tin hydrides with a stereogenic tin atom containing chiral 2-[(1-dimethylaminoalkyl)phenyl] ligands (DAAP). These reactions, which give the enantiomeric reduction products directly, are examples of a stereoselectivity in which a chiral reagent distinguishes between the enantiotopic faces of a radical in diastereomeric transition states (Figure 1) and are different from enantioselective reactions with chiral auxiliaries coordinated to the radical as described, for example, by Murakata et al.[7].

Results

Tin hydrides that contain chiral ligands are hydrogen donors which, in principle, can trap prochiral radicals enantioselectively without loss of chirality under free-radical conditions. We synthesized tin hydrides **1a−f** with a chiral DAAP ligand[8], hoping that the alkyl groups linked to the tin atom might cause a strong repulsive steric interaction with the alkyl group at the stereogenic centre of the chiral DAAP ligand and lead to the formation of one favoured diastereomer. However, we obtained mixtures of diastereomers (Table 1) which could not be separated, comparable to the results of Schumann et al.[9]. The diastereomers are configurationally stable at the tin atom[8].

Figure 1. Reaction coordinate of the hydrogen transfer from chiral tin hydrides to prochiral radicals: an example of an enantioselective elementary reaction

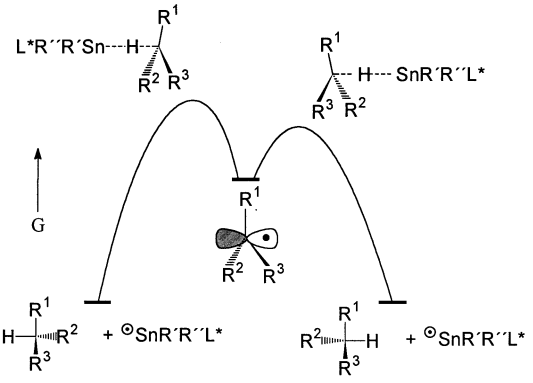

Table 1. Diastereomeric ratios of tin hydrides **1a−f**

	1a	**1b**	**1c**	**1d**	**1f**
dr	58:42	80:20	66:34	51:49	57:43

Tin hydrides **1** proved to be very efficient free-radical reducing agents[10]. α-Bromo esters **2** were readily reduced without any initiator added, even at −30°C (Scheme 1). Transfer of hydrogen from tin hydride **1** to prochiral radicals **5** leads to the formation of (*S*)-**4** and (*R*)-**4**, the ratio of which was determined by GC analysis. The reaction of α-bromo ester **2a** with tin hydride **1a** at −30°C led to the reduction products in a ratio of [(*S*)-**4a**]/[(*R*)-**4a**] = 55.1:44.9 (10% *ee*) (Table 2, entry 1). By changing the configuration

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of the DAAP ligand from tin hydride **1a** to tin hydride **1b**, inversion of the enantioselectivity is observed (Table 2, entries 1−3; Table 3, entry 1). Variation of the alkyl substituent R^2 of the α-bromo ester **2** shows that the stereoselectivity is strongly influenced by the steric effect of R^2. It is thus remarkable that the enantiomeric ratio of the reduction products **4** (Figure 2) decreases on going from [(*S*)-**4**]/[(*R*)-**4**] = 55.1:44.9 (R^2 = Me, Table 2, entry 1) through 54.5:45.5 (R^2 = Et, entry 4) to 51.8:48.2 (R^2 = *i*Pr, entry 7) and is reversed and dramatically increased to 37.4:62.6 (R^2 = *t*Bu, Table 3, entry 2). In contrast, α-bromo ester **2e** is reduced unselectively (R^1 = *n*Bu, R^2 = Me, Table 2, entry 10). We measured the temperature dependence of the enantioselectivity of the reduction of α-bromo esters **2a−d** (Tables 2, 3). The enantioselectivity decreases with rising temperature. The temperature effect was found to be different for **2d** > **2a** > **2b** > **2c**.

Scheme 1

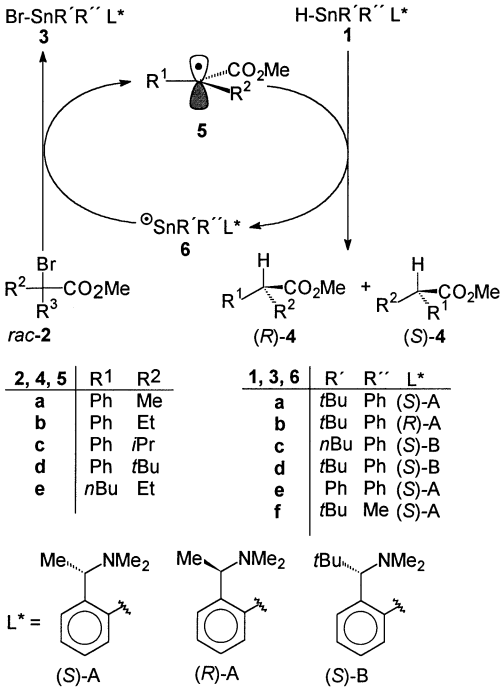


Table 2. Enantioselectivity of the reduction of α-bromo esters **2a−c**,**e** with tin hydride **1a** in the temperature range from −30 to 66°C[a]

Entry	**2**	*T* [°C]	Reaction time [h]	Conversion of **2** to **4** [%]	[(*S*)-**4**]/[(*R*)-**4**][a]
1	**a**	−30	10	99	55.1:44.9
2	**a**	20	1	98	53.1:46.9
3	**a**	66	0.5	98	51.0:49.0
4	**b**	−30	48	33	54.5:45.5
5	**b**	20	3	>99	51.9:48.1
6	**b**	66	1	92	51.0:49.0
7	**c**	−30	12	95	51.8:48.2
8	**c**	20	3	99	50.5:49.5
9	**c**	66	1	>99	50.3:49.7
10	**e**	−30	48	82	50.0:50.0

[a] [**1a**]/[**2**] = 1.5:1; solvent: THF.

Table 3. Enantioselectivity of the reduction of α-bromo ester **2a** at 20°C and of **2d** in the temperature range from −30 to 66°C by tin hydride **1b**[a]

Entry	**2**	[**1b**]/[**2**]	*T* [°C]	Reaction time [h]	Conversion of **2** to **4** [%]	[(*S*)-**4**]/[(*R*)-**4**]
1	**a**	1:2	20	1	49[b]	47.7:52.3
2	**d**	1.5:1	−30	14	20	62.6:37.4
3	**d**	2:1	20	2	98	53.2:46.8
4	**d**	1:8	20	2	11[b]	61.5:38.5
5	**d**	1.5:1	66	0.5	62	54.9:45.1

[a] Solvent: THF. − [b] Tin hydride **1b** was completely consumed at the end of the reaction.

The enantioselectivity of the reduction of α-bromo ester **2d** (Table 3, entries 3−4) depends on the ratio of tin hydride and substrate. For example, using a substrate ratio of [**1b**]/[**2d**] = 2:1, α-bromo ester **2d** was completely reduced and the enantiomeric ratio of the product was [(*S*)-**4d**]/[(*R*)-**4d**] = 53.2:46.8 at 20°C (Table 3, entry 3). However, using an excess of α-bromo ester **2d** ([**1b**]/[**2d**] = 1:8 (Table 3, entry 4), tin hydride **1b** was completely consumed at the end of the reaction and the enantiomeric ratio of [(*S*)-**4d**]/[(*R*)-**4d**] = 61.5:38.5 was significantly increased, which means that the major diastereomer of tin hydride **1b** reacts faster and less selectively than the minor diastereomer.

We synthesized tin hydride **1d** with a *t*Bu group instead of a Me group at the stereogenic centre of the DAAP ligand to investigate the influence of this substituent on the enantioselectivity of the hydrogen transfer. Surprisingly, we found that α-bromo ester **2** was reduced almost unselectively by tin hydride **1d**. The selectivity observed for the reduction of **2a** at room temperature was [(*S*)-**4a**]/[(*R*)-**4a**] = 49.1:50.9 (Table 4, entry 2). Tin hydride **1c** with the same DAAP ligand and the smaller *n*Bu group at the tin centre showed improved but still low enantioselectivity for the reduction of α-bromo ester **2a**, compared to tin hydride **1d** {[(*S*)-**4a**]/[(*R*)-**4a**] = 47.7:52.3 (Table 4, entry 1)}. The reversed enantioselectivity, compared to the results using tin hydride **1a** (Table 2, entry 2), is most remarkable.

Table 4. Enantioselectivity of the reduction of α-bromo ester **2a** by tin hydrides **1c−f** at room temperature

Entry	**1**	[**1**]/[**2a**]	Reaction time [h]	Conversion of **2** to **4** [%]	[(*S*)-**4**]/[(*R*)-**4**][a]
1	**c**	1.5:1[a]	1	96	47.7:52.3
2	**d**	1:3[a]	0.3	34	49.1:50.9
3	**e**	1.5:1[a]	2	99	50.0:50.0
4	**f**	1:5[b]	2	16	50.4:49.6

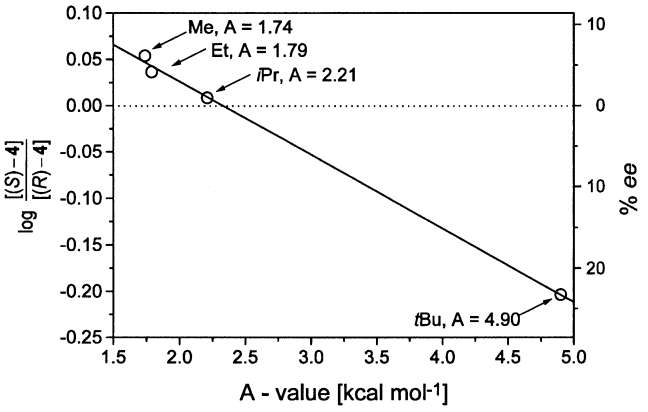
[a] Solvent: THF. − [b] Solvent: diethyl ether.

Tin hydride **1f** gave low enantioselectivities as well. For example, α-bromo ester **2a** was reduced at room temperature to give [(*S*)-**4a**]/[(*R*)-**4a**] = 50.4:49.6 (Table 4, entry 4). Tin hydride **1e** proved to be completely unselective in the reduction of α-bromo ester **2a** (Table 4, entry 3).

Discussion

The enantioselectivity of the hydrogen transfer is a result of the differentiation between the *Re* and *Si* face of the radicals **5** by the chiral tin hydride in the transition state. As can be seen from the results summarized in Tables 2−4, the observed enantioselectivities depend on the tin hydride used and on the substituents attached to the radical centre. The enantioselectivity is linearly correlated with the steric effect of the α substituent R^2 at the radical centre, decreasing with increasing steric effect of substituent R^2 going from methyl through ethyl to isopropyl and is reversed and highest for R^2 = *t*Bu (**2d**) (Figure 2). This can be rationalized by considering the differences of the steric effects of the substituents R^1 = Ph and R^2. It can be seen that with smaller differences in the steric effects between the largest substituent represented by the phenyl group (*A* value[11] = 2.87 kcal/mol) and the medium-sized alkyl substituent in radical **5a** (R^2 = Me, *A* value = 1.74 kcal/mol), **5b** (R^2 = Et, *A* value = 1.79 kcal/mol) and **5c** (R^2 = *i*Pr, *A* value = 2.21 kcal/mol) the observed enantioselectivities decrease. By introducing the *t*Bu group (*A* value = 4.9 kcal/mol) to the radical centre in **5d**, the preferred reduction product is the opposite enantiomer because in this case, the largest substituent is represented by the *t*Bu group and the medium-sized one by the phenyl group. The COOMe (*A* value = 1,27 kcal/mol) group is the smallest substituent in all cases.

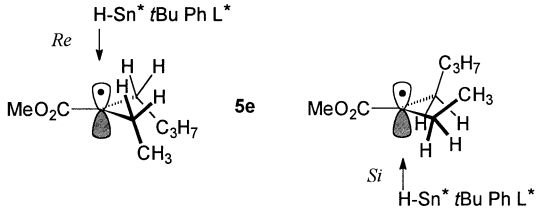
Figure 2. Correlation of the enantioselectivity of the hydrogen transfer from tin hydrides **1a** and **1b** to acyclic radicals RPhC•COOMe **5a−d** with steric substituent parameter *A*[11] of the alkyl substituents R (Table 2, entries 2, 5, 8); the inversed value of the enantiomeric ratio of reduction product **4d** (Table 3, entry 4) was used



Radical **5e** is reduced unselectively. This can be explained by a preferred conformation of radical **5e** in the transition state of hydrogen transfer. The alkyl groups are turned away from the attacking H donor. In this conformation no discrimination between the enantiotopic faces of the radical is possible (Figure 3). This also explains why radicals **5a** and **5b** show similar selectivities.

A remarkable and very important result is the difference in the reactivities and selectivities of the diastereomers of tin hydrides **1a** and **1b**. The major diastereomer reacts faster and almost unselectively. In contrast, the minor diastereomer reacts more slowly and with higher enantioselectivity. This can be rationalized considering the probable structures of the two diastereomers. The only existing X-ray structure analysis of a comparable tin hydride, *tert*-butyl[8-(dimethylamino)naphthyl][(−)-menthyl]tin hydride, gives evidence for a very weak donor−acceptor interaction of the dimethylamino group and the tin atom *trans* to the *tert*-butyl group[12]. Assuming the same donor−acceptor interaction in the case of tin hydrides **1**[8], the configuration of the two diastereomers can be obtained as given in Figure 4 for tin hydride **1b**. An inspection of the possible transition states of the hydrogen transfer to radicals **5** leads to a straightforward rationalization of the observed enantioselectivities (Figure 4). Based on steric effects in the transition state of the hydrogen transfer, in which the donor, hydrogen, and acceptor atoms assume a linear arrangement (Sn···H···C), diastereomer (R_C,S_{Sn})-**1b** should be able to distinguish between the faces of prochiral radicals such as **5d** (Figure 4a). In this transition state, the small substituent S = COOMe at the radical centre is presumably oriented beneath the dimethylamino group, the medium-sized substituent M = Ph is oriented beneath the methyl group and the large substituent L = *t*Bu is oriented in the least sterically hindered space between the *t*Bu and the Ph ligands of the tin hydride. Based on this model, the selective formation of (*S*)-**4d** is expected upon reduction of the α-bromo ester **2d** via radical **5d**. In the case of the reduction of α-bromo ester **2a** via radical **5a**, the selective formation of (*R*)-**4a** was expected and observed. On the other hand, diastereomer (R_C,R_{Sn})-**1b** should not be able to differentiate between the enantiotopic faces because the spaces between the *t*Bu and the Ph ligands and between the *t*Bu and the DAAP ligands are approximately equal (Figure 4b). Thus, assuming an approximately unselective reduction by the major diastereomer (R_C,R_{Sn})-**1b**, the enantioselectivity of the reduction of radical **5d** by the minor diastereomer (R_C,S_{Sn})-**1b** can be calculated from the data in Table 3 (entries 3 and 4) to be close to 100% at 20°C. This simple steric model of the interaction of hydrogen donor and acceptor in the transition state can also explain the other experimental results, such as the almost unselective reduction of α-bromo esters **2** by tin hydride **1d**. An inspection of the possible transition state of hydrogen transfer from diastereomer (S_C,R_{Sn})-**1d** to radical **5a** indicates that the small substituent S = COOMe is oriented beneath the *t*Bu group, the medium-sized substituent M = Me is oriented beneath the dimethylamino group and the large substituent L = Ph is oriented in the space between the phenyl group and the *t*Bu

Figure 3. Conformation of the prochiral radical **5e** in the transition state of the unselective hydrogen transfer from tin hydride **1**



ligand (Figure 5) to give (*R*)-**4a** with low selectivity, because the steric effect of the dimethylamino group is comparable to that of the *t*Bu group. Diastereomer (S_C,S_{Sn})-**1d** is expected to react completely unselectively, comparable to (R_C,R_{Sn})-**1b** (Figure 4b). The selectivities of tin hydrides **1c** and **1f** can be explained analogously. Tin hydride **1e**, bearing two phenyl ligands, is also expected to reduce radicals **5** unselectively, comparable to the unselective diastereomer of tin hydride **1b** (Figure 4b).

Figure 4. Probable transition-state structures of the hydrogen transfer to radical **5d** from (a) the minor diastereomer (R_C,S_{Sn})-**1b**, which is expected to occur selectively, and (b) the major diastereomer of tin hydride (R_C,R_{Sn})-**1b**, which is expected to occur unselectively

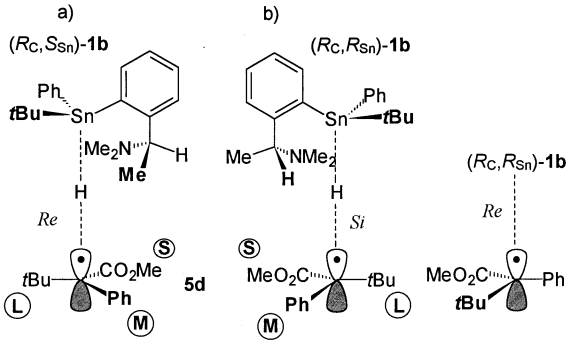
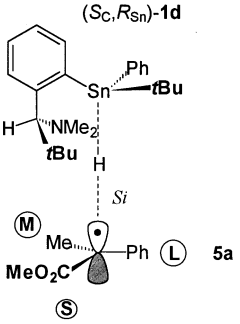


Figure 5. Probable transition-state structure of the hydrogen transfer to radical **5a** from diastereomer (S_C,R_{Sn})-**1d** of tin hydride **1d**, which is expected to reduce with very low selectivity



Conclusion

With the increasing use of radical reactions in organic chemistry, a more detailed understanding of the selectivities is of great importance. Especially important is the knowledge of the enantioselectivity of hydrogen transfer and the possibility of controlling it, since this step is frequently the decisive product-forming step in radical reactions. It has been shown that the enantioselectivity of hydrogen transfer from chiral tin hydrides to prochiral radicals is determined by steric interactions between the hydrogen donors and the prochiral radicals. The observed selectivities are strongly influenced by the steric effects of the substituents attached to the radical centre. The selectivities for the minor diastereomers of tin hydrides **1a** and **1b** are shown to be good. This shows that we have to focus on the synthesis of enantiomerically pure tin hydrides[5].

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Experimental Section

Melting points: Laboratory Devices Mel-Temp. − ^{1}H (300.1 MHz) and ^{13}C (75.47 MHz) NMR: Bruker AM 300, tetramethylsilane (TMS) as internal standard for ^{1}H NMR, solvent signals for ^{13}C NMR. − MS: Finnigan MAT 212; MAT 95 for HRMS. − Elemental analysis: FA 1108 CHNS-O Fisons Instr. or Mikroanalytisches Labor Beller, D-37004 Göttingen, Germany. − Analytical GC: Carlo Erba HRGC with FID detector and 25-m capillary column and heptakis(2,6-di-*O*-methyl-3-*O*-pentyl)-β-cyclodextrine phase diluted in 50% of OV-1701. Products were identified by comparison to retention times of independently synthesized reference compounds. − Tin hydrides **1** were synthesized as described[8]. All reactions with organometallic compounds were carried out using standard Schlenk techniques under dry, oxygen-free argon.

Methyl rac-2-Bromo-2-phenylpropanoate (**2a**)[13]: 2-Phenylpropanoic acid (1.34 g, 8.9 mmol) and 0.89 g (10 mmol) of NBS were dissolved in 20 ml of dry CCl_4. This suspension was irradiated with a 300-W sun lamp. After a short time, the reaction mixture started to reflux. The reaction was monitored by GC analysis. After complete conversion of the starting compound, the reaction mixture was cooled to 0°C and stirred for 20 min. The solid was filtered off and washed with small portions of CCl_4. The solvent was removed from the filtrate at reduced pressure. For esterification, diazomethane was added to the residue. After removal of the solvent the product was distilled at reduced pressure yielding 1.7 g (79%) of **2a**, b.p. 119−121°C/3 Torr[14a][14b]. − n_D^{20} = 1.5396.

Methyl rac-2-Bromo-2-phenylbutanoate (**2b**): In a 100-ml conical flask with reflux condenser and drying tube, 8.2 g (50 mmol) of 2-phenylbutanoic acid and 4.7 ml (13.5 g, 50 mmol) of phosphorous tribromide were heated at 60°C for 1 h. After cooling to room temperature, the lower layer was removed. Then 3.2 ml (10 g, 62.5 mmol) of bromine was added carefully through the condenser and the resulting mixture was heated at 100°C for 6 h. Small portions of bromine were added during this time until the colour of the bromine did not disappear. After completion of the reaction, the solution was cooled to 0°C and 25 ml of dry methanol was added. After the addition, the resulting solution was stirred for 1 h and was decolourized by addition of Na_2CO_3. Filtration and removal of the solvent gave the crude product which was distilled at reduced pressure yielding 8.61g (67%) of **2b**, b.p. 132°C/4.5 Torr. − n_D^{20} = 1.5409. − ^{1}H NMR ($CDCl_3$): δ = 7.2−7.5 (m, 5 H, aromatic H), 3.79 (s, 3 H, OCH_3), 2.49 (m, 2 H, 3-H), 1.0 (t, 3 H, 4-H). − ^{13}C NMR ($CDCl_3$): δ = 171.04 (C=O), 139.69, 128.32, 128.17, 126.96, 69.97 (C-Br), 53.34 (OCH_3), 35.62 (C-3), 10.46 (C-4). − MS/CI (isobutane); *m/z* (%): 259/257 (5/6) [MH^+], 177 (100) [M^+ − Br]. − MS/EI (70 eV); *m/z* (%): 177 (54) [M^+ − Br], 121 (100) [$C_8H_9O^+$], 117 (81), 91 (47) [$C_7H_7^+$], 77 (27) [$C_6H_5^+$], 59 (82) [$C_2H_3O_2^+$]. − $C_{11}H_{14}BrO_2$: calcd. 257.0164; found 257.0162 {HRMS/CI (isobutane): [MH^+]}.

Methyl rac-2-Bromo-3-methyl-2-phenylbutanoate (**2c**): Analogously to the preparation of **2b**, 1 g (15.62 mmol) of 3-methyl-2-phenylbutanoic acid was treated with PBr_3/Br_2 followed by the addition of methanol. The product was obtained after distillation at reduced pressure yielding 1.99 g (47%) of **2c**, b.p. 105−107°C/1.5 Torr. − n_D^{20} = 1.5496. − ^{1}H NMR ($CDCl_3$): δ = 7.40−7.65 (m, 2 H, aromatic H), 7.2−7.4 (m, 3 H, aromatic H), 3.73 (s, 3 H, OCH_3), 2.72 (m, 1 H, 3-H), 1.11 [d, ^3J(CH,CH_3') = 6.47 Hz, 3 H, CH_3'], 0.848 [d, ^3J(CH,CH_3'') = 6.61 Hz, 3 H, CH_3'']. − ^{13}C NMR ($CDCl_3$): δ = 170.85 (C=O), 138.16, 128.44, 128.02, 127.84, 58.46

(C-Br), 53.32 (OCH_3), 37.89 (CH), 20.20 (CH_3'), 18.57 (CH_3''). – MS/CI (isobutane); *m/z* (%): 273/271 (49/58) [MH^+], 191 (100) [M^+ – Br]. – MS/EI (70 eV); *m/z* (%): 271 (72) [M^+], 269 (78) [M^+], 230 (29) [$M^+ - C_3H_5$], 228 (30) [$M^+ - C_3H_5$], 191 (69) [M^+ – Br], 131 (68), 121 (58), 73 (100) [$C_3H_5O_2^+$]. – $C_{12}H_{15}BrO_2$: calcd. 271.0334; found 271.0248 {HRMS/CI (isobutane): [MH^+]}.

Methyl rac-2-Bromo-3,3-dimethyl-2-phenylbutanoate (**2d**): Analogously to the preparation of **2a**, 4.2 g (20.4 mmol) of methyl 3,3-dimethyl-2-phenylbutanoate was treated with 5.5 g (61.2 mmol) of NBS for 24 h. The product was purified by column chromatography and distillation at reduced pressure. The product solidified after standing at room temperature, yielding 3.9 g (67%) of **2d**, m.p. 52–54°C (methanol), b.p. 145–147°C/3 Torr. – ^{1}H NMR ($CDCl_3$): δ = 7.39–7.47 (m, 2 H, aromatic H), 7.35–7.26 (m, 3 H, aromatic H), 3.74 (s, 1 H, OCH_3), 1.21 [s, 9 H, $C(CH_3)_3$]. – ^{13}C NMR ($CDCl_3$): δ = 170.76 (C=O), 137.53, 128.35, 127.79, 126.92 (aromatic C), 57.98 (CBr), 52.62 (OCH_3), 40.59 [$C(CH_3)_3$], 27.53 [br., $C(CH_3)_3$]. – MS/CI (isobutane); *m/z* (%): 285/283 (14/15) [MH^+], 205 (100) [M^+ – Br]. – MS/EI (70 eV); *m/z* (%): 230 (54), 228 (56), 198 (31) [$C_8H_5OBr^+$], 196 (31) [$C_8H_5OBr^+$] , 91 (56) [$C_7H_7^+$], 73 (44) [$C_3H_5O_2^+$], 57 (100) [$C_4H_9^+$]. – $C_{13}H_{17}BrO_2$ (284.0): calcd.C 54.97, H 6.03; found 54.66, H 6.31.

Methyl rac-2-Bromo-2-ethyl-hexanoate (**2e**): Analogously to the preparation of **2b**, 10 g (69.8 mmol) of 2-ethylhexanoic acid was treated with PBr_3/Br_2 followed by esterification with methanol. The crude product was distilled at 1 Torr with a 30-cm Vigreux column yielding 13.6 g (83%) of **2e**, b.p. 88°C/1 Torr. – n_D^{20} = 1.4618. – ^{1}H NMR ($CDCl_3$): δ = 3.74 (s, 3 H, OCH_3), 2.11 (m, 2 H, 5-H), 2.04 (m, 2 H, 4-H), 1.31 (m, 2 H, 3-H), 1.29 (m, 2 H, CH_2CH_3), 0.94 (t, ^3J = 7.31 Hz, 3 H, CH_2CH_3), 0.88 (t, ^3J = 6.99 Hz, 3 H, 6-H). – ^{13}C NMR ($CDCl_3$): δ = 171.38 (C=O), 68.77 (CBr), 52.82 (OCH_3), 39.32 (CH_2CH_3), 32.93 (C-3), 27.63 (C-4), 22.46 (C-5), 13.75 (CH_2CH_3), 9.92 (C-6). – MS/CI (isobutane); *m/z* (%): 239/237 (89/100) [MH^+], 157 (34) [M^+ – Br]. – MS/EI(70 eV); *m/z* (%): 182/180 (25/23) [$M^+ - C_4H_8$], 157 (57) [M^+ – Br], 125 (26) [$C_7H_9O_2^+$], 97 (100) [$C_9H_{11}^+$], 87 (21) [$C_4H_7O_2^+$], 73 (24) [$C_3H_5O_2^+$], 56 (92) [$C_4H_8^+$]. – $C_9H_{18}BrO_2$ (237.1): calcd. C 45.58, H 7.23; found C 45.69, H 7.23.

Reduction of α-Bromo Esters **2**: A typical reduction experiment was performed as follows: To a solution of 0.1–1 mmol of the α-bromo ester **2** in 1–10 ml of THF, a corresponding amount of tin hydride was added (see Tables 2–4). The reaction was monitored by GC analysis. The solvent was removed in vacuo and the residue was treated with pentane. A white solid formed which was filtered off. The pentane solution was filtered through a short column of silica gel and the products were eluted with pentane/diethyl ether (20:1). The enantiomeric ratio was determined by GC analysis. The products were identified by comparison to retention times of independently synthesized reference compounds.

☆ Dedicated to Professor *Manfred Weidenbruch* on the occasion of his 60th birthday.

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