Enantioselective Sulfur-*Michael* Addition of Thioacetic Acid to Nitroalkenes Catalyzed by Bifunctional Amine-Thiourea Catalysts

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An enantioselective *Michael* addition of thioacetic acid (AcSH) to nitroalkenes, catalyzed by a leucine-derived bifunctional amine–thiourea, was developed with high yields and moderate enantioselectivities. The thiourea-ammonium salt formed in the reaction is identified as the active catalyst, and the multiple H-bonding system is responsible for the stereocontrol. The resulting thioester products are useful intermediates for the synthesis of enantiomerically enriched S-containing compounds.

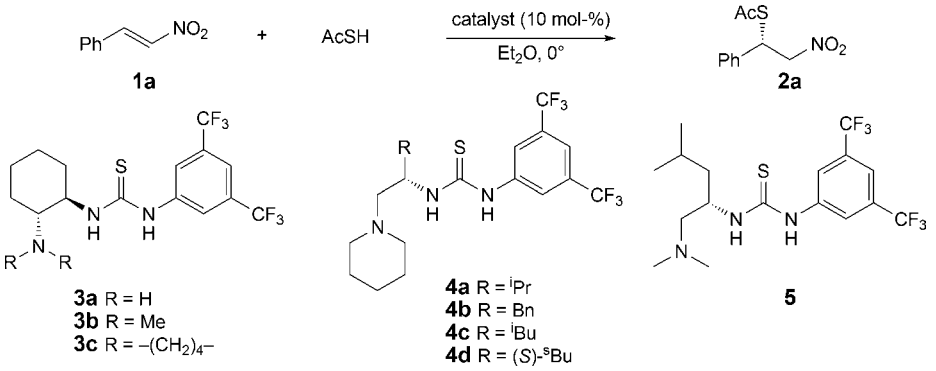
Introduction. – The importance of chiral organosulfur compounds has been widely recognized in natural products, biochemistry, and pharmaceutical chemistry. Thus, various synthetic methods for chiral S-containing compounds have been developed during recent years [1]. The asymmetric *Michael* addition of sulfur nucleophiles to activated alkenes, known as asymmetric sulfur-*Michael* addition (SMA), creates a center of chirality at the S-bound C-atom and provides an effective solution to the synthesis of S-centered optically active compounds [2]. Alkyl or aryl thiols [3], thiocarboxylic acids [4][5], and Na_2SO_3 [6] are appropriate S-nucleophiles for the asymmetric SMAs. Lately, AcSH has attracted much interest, since it was introduced in the asymmetric SMA to β-nitrostyrene with low-to-moderate enantioselectivity by *Wang* and co-worker [4a]. Subsequently, chiral *N*-sulfinylurea and squaramide catalysts have been successfully used in the enantio- and diastereoselective SMAs of thioacetic acid to nitroalkenes [4b–4e]. The asymmetric SMA involving AcSH and α,β-unsaturated ketones was catalyzed either with cinchona alkaloids in the past, or recently with amine-thiourea/urea catalysts; only low-to-moderate enantioselectivities were achieved [5]. Considering the convenient introduction of a chiral S-bound C-atom to the compounds and subsequent transformation to other S-containing molecules, *e.g.*, thiols or sulfonic acids, the examples employing AcSH as the nucleophile in the asymmetric SMA are lacking, and extension of the catalytic systems are highly desirable.

Bifunctional amine–thiourea catalysis has emerged as a powerful tool for promotion of several asymmetric reactions and attracted special interest in recent years [7]. Various chiral scaffolds have been involved in the synthesis of the catalysts, for example, (*R*,*R*)-cyclohexane-1,2-diamine and cinchona alkaloids. Amino acids, as commercially available and inexpensive sources of chirality, can be converted to amine–thiourea catalysts, and this class of catalysts has been applied to asymmetric *Michael* additions, *Mannich* reactions, and *Friedel–Crafts* reactions, *etc.* [8]. To the best

of our knowledge, asymmetric SMA, induced by amino acid derived amine–thiourea catalysts, has not been attempted yet. Herein, we report our study on the asymmetric SMA of AcSH to nitroalkenes, catalyzed with leucine-derived bifunctional catalyst, with high yield and up to 70% ee.

Results and Discussion. – First, amine–thiourea catalysts **3** (1-(2-aminocyclohexyl)-3-[3,5-bis(trifluoromethyl)phenyl]thioureas) based on (*R*,*R*)-cyclohexane-1,2-diamine and **4** (1-[3,5-bis(trifluoromethyl)phenyl]-3-[piperidin-1-ylalkyl]thioureas), derived from L-amino acids, were synthesized and tested in the enantioselective sulfur-*Michael* addition of AcSH to (*E*)-*β*-nitrostyrene ((*E*)-1-nitro-2-phenylethene; **1a**). As shown in *Table 1*, the structure of the amine–thiourea catalysts played an important role in the stereocontrol of the reaction. Catalyst **3a** bearing a primary amine group afforded the product **2a** with high yield but low enantioselectivity, while the enantioselectivity was increased with the tertiary amine–thiourea **3b**. Catalyst **3c** with a bulkier amino group provided results similar to those with catalyst **3b** (*Table 1*, *Entries 1–3*). The reactions were complete within 0.5 h when catalyzed with 10 mol-% of **4**, and enantioselectivities in the range of 38–53% were observed. Among the four catalysts derived from different L-amino acids, leucine-derived **4c** proved to be preferable (*Table 1*, *Entries*

Table 1. *Asymmetric* Michael *Addition of AcSH to (*E*)-β-Nitrostyrene Catalyzed by Organocatalysts*[a])



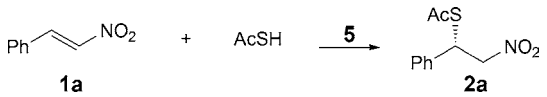
Entry	Catalyst	Yield [%][b])	ee [%][c])
1	**3a**	91	–30
2	**3b**	99	–51
3	**3c**	96	–50
4	**4a**	98	41
5	**4b**	91	38
6	**4c**	94	53
7	**4d**	93	40
8	**5**	96	55

[a]) The reaction was carried out with (*E*)-*β*-nitrostyrene (29.8 mg, 0.20 mmol) and AcSH (30.5 mg, 0.028 ml, 0.40 mmol) in the presence of 10 mol-% organocatalyst in 2 ml of Et_2O at 0° for 0.5 h. [b]) Yield of isolated **2a**. [c]) Determined by HPLC analysis with an *AS-H* chiral column; – means (*R*)-form in excess.

4 – 7). The replacement of the piperidin-1-yl group in **4c** with the Me_2N group provided catalyst **5**, which promoted the reaction with 96% yield and 55% ee, *i.e.*, the best result attained (*Table 1*, *Entry 8*).

The reaction conditions were further optimized by using catalyst **5**, and the results are compiled in *Table 2*. First, different solvents were examined, and Et_2O turned out to be the best medium for the reaction regarding the enantioselectivity (*Table 2*, *Entries 1 – 10*). The reaction in ^{i}PrOH resulted in a dramatic loss of the stereoselectivity, probably due to the strong H-bond donor ability of the alcohol. The reactions displayed little differences when carried out with 10 mol-% of AcOH or PhCOOH as additive, and this phenomenon indicated that the interaction between the thioacetate and the catalyst/(*E*)-*β*-nitrostyrene (**1a**) was weak, accordingly the key to stereocontrol was the coordination state between the catalyst and **1a** (*Table 2*, *Entries 11* and *12*). Changing the substrate-addition order, *i.e.*, adding **1a** to a solution of catalyst **5** and AcSH also provided the product **2a** with 55% ee (*Table 2*, *Entry 13*). Considering that the acid–base neutralization reaction is much faster than the *Michael* addition, these

Table 2. *Optimization of Reaction Conditions for Asymmetric* Michael *Addition of AcSH to (*E*)-β-Nitrostyrene*[a])



1a **2a**

Entry	Solvent	*T* [°]	Yield [%][b])	ee [%][c])
1	Et_2O	0	96	55
2	$^iPr_2O$	0	95	53
3	^{t}BuOMe	0	97	54
4	THF	0	94	47
5	CH_2Cl_2	0	98	52
6	$CHCl_3$	0	90	44
7	Toluene	0	96	48
8	Acetone	0	96	40
9	AcOEt	0	91	48
10	^{i}PrOH	0	94	23
11[d])	Et_2O	0	98	55
12[e])	Et_2O	0	93	56
13[f])	Et_2O	0	97	55
14	Et_2O	– 10	94	59
15	Et_2O	– 20	96	61
16	Et_2O	– 30	96	61
17[g])	Et_2O	– 20	93	55
18[h])	Et_2O	– 20	94	59
19[i])	Et_2O	– 20	90	57

[a]) The reaction was carried out with (*E*)-*β*-nitrostyrene (14.9 mg, 0.10 mmol) and AcSH (15.2 mg, 0.014 ml, 0.20 mmol) in the presence of 10 mol-% organocatalyst **5** in 1 ml of solvent. [b]) Yield of isolated **2a**. [c]) Determined by HPLC analysis with an *AS-H* chiral column. [d]) Ten mol-% PhCOOH was added. [e]) Ten mol-% AcOH was added. [f]) (*E*)-*β*-Nitrostyrene (**1a**) was added to a solution of **5** and AcSH. [g]) Five mol-% catalyst. [h]) Two mol-% catalyst. [i]) One mol-% catalyst.

results indicated that the AcSH reacted with the tertiary amino group of catalyst **5** first, generating thioacetate and **5** · H^+. Then, (*E*)-*β*-nitrostyrene (**1a**) was activated by **5** · H^+ and attacked by thioacetate, thus generating product **2a** with 55% ee. Racemization of the enantiomerically enriched product occurred slowly, when the product was treated with catalyst **5** in Et_2O under neutral conditions, whereas no racemization was observed under acidic conditions. Considering the reversibility of the SMA, catalyst **5** itself failed to arrange the reaction enantioselectively, while **5** · H^+, with an additional H-bond donor provided by the ammonium salt, seemed to be the real catalyst for the reaction. The multiple H-bonding system including two thiourea H-bondings and an ammonium salt H-bonding in **5** · H^+ seemed to be essential to attain good stereocontrol. The benefit of the multiple H-bonding system in asymmetric reactions was also reported in the literature (*Scheme*) [3r][9]. These studies indicated that the reaction must be run under acidic conditions, and use of excess AcSH was necessary.

Lowering the reaction temperature to $-20°$ improved the product ee, which remained unchanged when the reaction was carried out at $-30°$ (*Table 2*, *Entries 14–16*). The selectivity slightly decreased with lower catalyst loading, and 2 mol-% catalyst loading furnished **2a** with 94% yield and 59% ee (*Table 2*, *Entries 17–19*). The absolute configuration of product **2a** was determined as (*S*) by comparison of its specific rotation with that reported in [4d].

The scope of the substrates was investigated after establishing the best reaction conditions. The present system tolerated electron-withdrawing or electron-donating groups on the aromatic ring of the substrates, and, generally, *ortho*-substitution on the aromatic ring had a beneficial impact on the enantioselectivity (*Table 3*, *Entries 1–10*). The phenomenon was also observed in other asymmetric *Michael* additions. For substrate **1f**, the NO_2 group on the aromatic ring probably interfered with the H-bond interaction between the catalyst and the substrate, thus lowering the enantioselectivity. Substrate **1k** bearing a naphthalen-1-yl group reacted with AcSH to give product **2k** with 93% yield and 70% ee. Besides the aromatic nitroalkenes, aliphatic nitroalkenes

Scheme. *Multiple H-bonding System Used in This Work and Examples Reported in Literature*

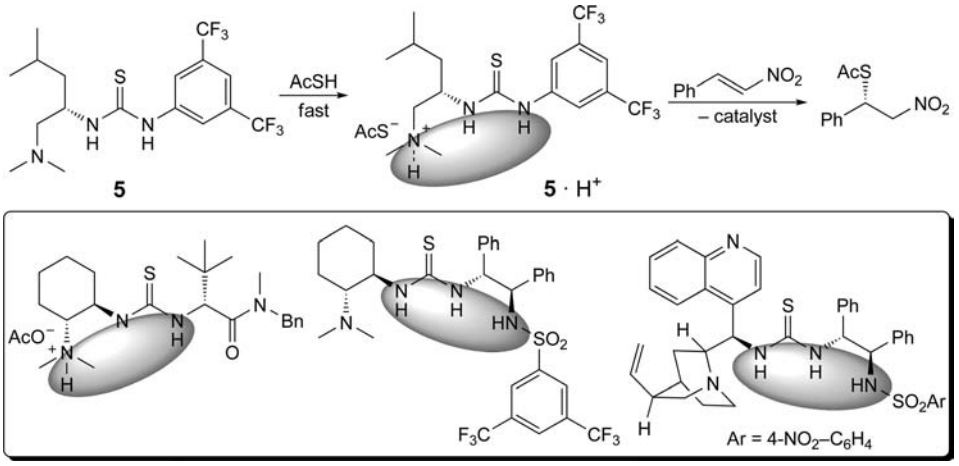
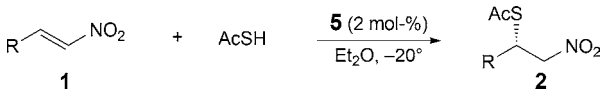


Table 3. Michael *Addition Reactions of AcSH to (*E*)-Nitroalkenes*[a])



Entry	**2**	R	Yield [%][b])	ee [%][c])
1	**2a**	Ph	94	59
2	**2b**	2-Cl–C_6H_4	96	62
3	**2c**	4-Cl–C_6H_4	90	57
4	**2d**	2,6-Cl_2–C_6H_3	92	49
5	**2e**	4-Br–C_6H_4	99	58
6	**2f**	2-O_2N–C_6H_4	89	38
7	**2g**	4-Me–C_6H_4	96	64
8	**2h**	4-MeO–C_6H_4	98	62
9	**2i**	3-MeO–C_6H_4	96	59
10	**2j**	2,4-$(MeO)_2$–C_6H_3	91	68
11	**2k**	Naphthalen-1-yl	93	70
12	**2l**	^{i}Pr	85	57

[a]) The reaction was carried out with (*E*)-nitroalkene (0.10 mmol) and AcSH (15.2 mg, 0.014 ml, 0.20 mmol) in the presence of 2 mol-% organocatalyst **5** in Et_2O at $-20°$. [b]) Yield of isolated product. [c]) Determined by HPLC analysis with an *AS-H* or *AD-H* chiral column.

were also suitable substrates for this catalysis system with high yields and moderate ee values (*Table 3*, *Entry 12*).

3. Conclusions. – We have developed the L-leucine-derived bifunctional thiourea-catalyzed asymmetric sulfur-*Michael* addition of AcSH to nitroalkenes with a broad substrate scope, high yields, and up to 70% ee. Detailed analysis of the catalytic system revealed that the catalyst reacts with AcSH prior to nitroalkenes, and a multiple H-bond system seems to be necessary to achieve a good stereocontrol. This method expands the application scope of the amino acid-derived amine–thiourea catalysts and offers a convenient way to chiral organosulfur compounds.

Experimental Part

General. Column chromatography (CC): silica gel (SiO_2, 200–300 mesh). M.p.: *Yanaco MP-500*; uncorrected. The ee values [%] were determined by chiral HPLC using an *Agilent 1260 LC* instrument with a *Daicel Chiralpak AS-H* or *AD-H* column. Optical rotations: *Anton Paar MCP 200* polarimeter. ^{1}H- and ^{13}C-NMR spectra: *Bruker* at 300 and 400 MHz, resp.; in $CDCl_3$; δ in ppm rel. to Me_4Si as internal standard; *J* in Hz. HR-MS: *Agilent* LC/MDF TOF mass spectrometer; in *m*/*z*.

General Procedure for Asymmetric Sulfur-Michael *Addition of AcSH to Nitroalkenes.* A soln. of nitroalkene (0.1 mmol) and catalyst **5** (0.83 mg, 0.002 mmol) was stirred at $-20°$ in Et_2O (1 ml). AcSH (15.2 mg, 0.014 ml, 0.2 mmol) was added, and the reaction was monitored by TLC. After completion of the reaction, the soln. was washed quickly with sat. aq. $NaHCO_3$ soln. (3 × 1 ml), and eluted immediately through a silica-gel plug with Et_2O. After evaporation of the solvent *in vacuo*, the residue was purified by CC to give the desired product **2**.

S-*[(1*S*)-2-Nitro-1-phenylethyl] Ethanethioate* (**2a**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70:30; 1.0 ml/min; λ 220 nm): t_R(major) 10.2, t_R(minor) 13.4 min. Colorless crystals. Yield: 94%. M.p. 126–129°

([4d]: 122–124°). $[\alpha]_D^{22} = +143.4$ ($c = 0.8$, $CHCl_3$) ([4d]: $[\alpha]_D^{22} = +136.4$ ($c = 0.9$, CH_2Cl_2)). ^{1}H-NMR (300 MHz, $CDCl_3$): 2.36 (*s*, Me); 4.84 (*d*, $J = 7.5$, CH_2); 5.29 (*t*, $J = 7.5$, CH); 7.32–7.35 (*m*, 5 arom. H). ^{13}C-NMR (75 MHz, $CDCl_3$): 30.3; 44.4; 77.9; 127.7; 128.8; 129.1; 135.6; 193.3.

S-*[(1S)-1-(2-Chlorophenyl)-2-nitroethyl] Ethanethioate* (**2b**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 9.6, t_R(minor) 13.3 min. Colorless oil. Yield: 96%. $[\alpha]_D^{22} = +15.1$ ($c = 0.9$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.37 (*s*, Me); 4.87 (*dd*, $J = 6.4$, 13.6, 1 H of CH_2); 5.00 (*dd*, $J = 8.8$, 13.6, 1 H of CH_2); 5.71 (*dd*, $J = 6.4$, 8.8, CH); 7.25–7.27 (*m*, 2 arom. H); 7.36–7.42 (*m*, 2 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.2; 41.9; 76.6; 127.4; 129.5; 130.0; 130.5; 133.2; 138.7; 193.0. HR-ESI-MS: 281.9965 ($[M+Na]^+$, $C_{10}H_{10}ClNNaO_3S^+$; calc. 281.9968).

S-*[(1S)-1-(4-Chlorophenyl)-2-nitroethyl] Ethanethioate* (**2c**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 12.9, t_R(minor) 16.8 min. Colorless crystals. Yield: 90%. M.p. 60–63° ([4e]: 67–68°). $[\alpha]_D^{22} = +144.8$ ($c = 0.9$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.36 (*s*, Me); 4.79 (*dd*, $J = 9.0$, 13.4, 1 H of CH_2); 4.84 (*dd*, $J = 6.6$, 13.4, 1 H of CH_2); 5.25 (*dd*, $J = 6.6$, 9.0, CH); 7.26 (*d*, $J =$ 8.6, 2 arom. H); 7.33 (*d*, $J = 8.6$ Hz, 2 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.3; 43.7; 77.7; 129.1; 129.3; 134.2; 134.7; 193.0.

S-*[(1S)-1-(2,6-Dichlorophenyl)-2-nitroethyl] Ethanethioate* (**2d**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 8.6, t_R(minor) 9.0 min. Colorless crystals. Yield: 92%. M.p. 66–67°. $[\alpha]_D^{22} = +76.2$ ($c = 1.0$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.38 (*s*, Me); 4.87 (*dd*, $J = 6.8$, 13.2, 1 H of CH_2); 5.22 (*dd*, $J = 8.8$, 13.2, 1 H of CH_2); 6.43 (*dd*, $J = 6.8$, 8.8, CH); 7.20 (*t*, $J = 8.0$, 1 arom. H); 7.31 (*d*, $J = 8.0$, 1 arom. H); 7.37 (*d*, $J = 8.0$, 1 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.0; 39.8; 76.2; 129.2; 129.6; 130.2; 132.0; 135.4; 136.2; 192.6. HR-ESI-MS: 315.9579 ($[M+Na]^+$, $C_{10}H_9Cl_2NNaO_3S^+$; calc. 315.9578).

S-*[(1S)-1-(4-Bromophenyl)-2-nitroethyl) Ethanethioate* (**2e**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 11.5, t_R(minor) 13.7 min. Colorless crystals. Yield: 99%. M.p. 74–76°. $[\alpha]_D^{22} = +164.0$ ($c = 0.4$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.36 (*s*, Me); 4.80 (*dd*, $J = 9.2$, 13.2, 1 H of CH_2); 4.82 (*dd*, $J = 6.8$, 13.2, 1 H of CH_2); 5.24 (*dd*, $J = 6.8$, 9.2, CH); 7.18–7.21 (*m*, 2 arom. H); 7.46–7.49 (*m*, 2 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.3; 43.8; 77.6; 122.9; 132.3; 134.8; 192.9. HR-ESI-MS: 325.9459 ($[M+Na]^+$. $C_{10}H_{10}BrNNaO_3S^+$; 325.9462).

S-*[(1S)-1-(2-Nitro-1-(2-nitrophenyl)ethyl) Ethanethioate* (**2f**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 19.2, t_R(minor) 24.9 min. Colorless oil. Yield: 89%. $[\alpha]_D^{22} = +3.4$ ($c = 0.8$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.35 (*s*, Me); 4.96 (*dd*, $J = 6.4$, 13.6, 1 H of CH_2); 5.03 (*dd*, $J = 7.6$, 13.6, 1 H of CH_2); 5.87 (*dd*, $J = 6.4$, 7.6, CH); 7.49–7.53 (*m*, 1 arom. H); 7.57–7.66 (*m*, 2 arom. H); 7.98–8.00 (*m*, 1 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.1; 40.7; 77.5; 125.5; 129.7; 130.9; 131.4; 133.7; 148.5; 192.6. HR-ESI-MS: 293.0203 ($[M+Na]^+$, $C_{10}H_{10}N_2NaO_5S^+$; calc. 293.0208).

S-*[(1S)-1-(4-Methylphenyl)-2-nitroethyl] Ethanethioate* (**2g**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 8.6, t_R(minor) 11.3 min. Colorless crystals. M.p. 80–81° ([4b]: 91–92°). Yield: 96%. $[\alpha]_D^{22} = +153.5$ ($c = 0.9$, $CHCl_3$) ([4b]: $[\alpha]_D^{23} = -159.1$ ($c = 1.0$, $CHCl_3$; (*R*)-enantiomer). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.32 (*s*, Me); 2.34 (*s*, Me); 4.82 (*dd*, $J = 8.4$, 13.2, 1 H of CH_2); 4.82 (*dd*, $J = 7.2$, 13.2, 1 H of CH_2); 5.25 (*dd*, $J = 7.2$, 8.4, CH); 7.14 (*d*, $J = 8.4$, 2 arom. H); 7.19 (*d*, $J = 8.4$, 2 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 21.1; 30.3; 44.2; 78.0; 127.6; 129.8; 132.5; 138.7; 193.4.

S-*[(1S)-1-(4-Methoxyphenyl)-2-nitroethyl] Ethanethioate* (**2h**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 20.1, t_R(minor) 30.8 min. Colorless crystals. M.p. 111–114° ([4b]: 105–106°). Yield: 98%. $[\alpha]_D^{22} = +139.9$ ($c = 1.1$, $CHCl_3$) ([4b]: $[\alpha]_D^{23} = -234.3$ ($c = 1.0$, $CHCl_3$; (*R*)-enantiomer). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.34 (*s*, Me); 3.78 (*s*, MeO); 4.80 (*dd*, $J = 9.2$, 13.2, 1 H of CH_2); 4.81 (*dd*, $J = 6.8$, 13.2, 1 H of CH_2); 5.24 (*dd*, $J = 6.4$, 9.2, CH); 6.86 (*d*, $J = 8.8$, 2 arom. H); 7.23 (*d*, $J = 8.8$, 2 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.3; 44.1; 55.3; 78.1; 114.5; 127.4; 128.9; 159.8; 193.5.

S-*[(1S)-1-(3-Methoxyphenyl)-2-nitroethyl] Ethanethioate* (**2i**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70 : 30; 1.0 ml/min; λ 220 nm): t_R(major) 11.4, t_R(minor) 12.6 min. Colorless oil. Yield: 96%. $[\alpha]_D^{22} = +42.1$ ($c = 1.0$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.35 (*s*, Me); 3.79 (*s*, MeO); 4.82 (*d*, $J = 8.0$, CH_2); 5.26 (*t*, $J = 8.0$, CH); 6.83–6.89 (*m*, 3 arom. H); 7.23–7.28 (*m*, 1 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.3; 44.4; 55.3; 77.9; 113.6; 114.1; 119.8; 130.2; 137.1; 160.0; 193.3. HR-ESI-MS: 278.0461 ($[M+Na]^+$, $C_{11}H_{13}NNaO_4S^+$; calc. 278.0463).

S-*[(1S)-1-(2,4-Dimethoxyphenyl)-2-nitroethyl] Ethanethioate* (**2j**) [4a]. Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70:30; 1.0 ml/min; λ 220 nm): t_R(major) 9.9, t_R(minor) 11.5 min. Colorless oil. Yield: 91%. $[\alpha]_D^{22} = +131.1$ ($c = 0.9$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.32 (*s*, Me); 3.78 (*s*, MeO); 3.85 (*s*, MeO); 4.77 (*dd*, $J = 6.4, 13.2$, 1 H of CH_2); 4.95 (*dd*, $J = 8.8, 12.8$, 1 H of CH_2); 5.43 (*dd*, $J = 6.4, 9.2$, CH); 6.41–6.45 (*m*, 2 arom. H); 7.19 (*d*, $J = 8.0$, 1 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.2; 41.2; 55.3; 55.6; 77.2; 99.2; 104.5; 116.0; 130.6; 158.3; 161.3; 194.2.

S-*[(1S)-1-(Naphthalen-1-yl)-2-nitroethyl] Ethanethioate* (**2k**). Chiral HPLC (*AS-H*; hexane/^{i}PrOH 70:30; 1.0 ml/min; λ 220 nm): t_R(major) 10.8, t_R(minor) 16.0 min. Colorless crystals. Yield: 93%. M.p. 69–69°. $[\alpha]_D^{22} = +133.8$ ($c = 1.1$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.35 (*s*, Me); 4.96 (*dd*, $J = 7.2, 9.6$, 1 H of CH_2); 5.10 (*dd*, $J = 8.8, 9.6$, 1 H of CH_2); 6.16 (*dd*, $J = 7.2, 8.8$, CH); 7.41 (*t*, $J = 7.6$, 1 arom. H); 7.46 (*d*, $J = 7.6$, 1 arom. H); 7.52 (*t*, $J = 7.2$, 1 arom. H); 7.58–7.62 (*m*, 1 arom. H); 7.81 (*d*, $J = 8.0$, 1 arom. H); 7.86 (*d*, $J = 8.0$, 1 arom. H); 8.10 (*d*, $J = 8.4$, 1 arom. H). ^{13}C-NMR (100 MHz, $CDCl_3$): 30.1; 40.2; 77.4; 122.5; 125.1; 126.3; 127.1; 129.2; 129.5; 130.4; 131.1; 134.1; 193.6. HR-ESI-MS: 298.0514 ($[M + Na]^+$, $C_{14}H_{13}NNaO_3S^+$; calc. 298.0514).

S-*[(2S)-3-Methyl-1-nitrobutan-2-yl] Ethanethioate* (**2l**) [4e]. Chiral HPLC (*AD-H*; hexane/^{i}PrOH 70:30; 1.0 ml/min; λ 220 nm): t_R(major) 5.3, t_R(minor) 5.6 min. Colorless oil. Yield: 85%. $[\alpha]_D^{22} = -1.6$ ($c = 0.4$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 0.97 (*d*, $J = 6.8$, Me); 1.02 (*d*, $J = 6.8$, Me); 2.03–2.11 (*m*, CH); 2.37 (*s*, Me); 4.14–4.19 (*m*, CH); 4.54 (*dd*, $J = 6.8, 13.2$, 1 H of CH_2); 4.57 (*dd*, $J = 7.6, 13.2$, 1 H of CH_2). ^{13}C-NMR (100 MHz, $CDCl_3$): 18.5; 20.2; 29.4; 30.7; 47.5; 77.0; 193.7.

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