Resolution of Pentafluorophenyl Active Esters Using (*S*)-4-Phenyloxazolidin-2-thione

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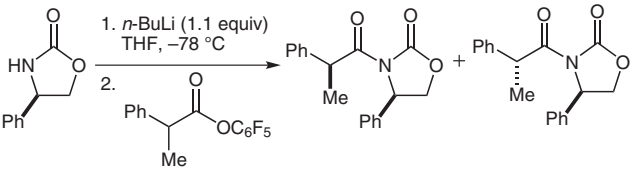
Received 3 December 2008

Abstract: A series of structurally related racemic pentafluorophenyl active esters were resolved using an equimolar amount of (*S*)-4-phenyloxazolidin-2-thione. The levels of diastereocontrol were found to be excellent (>86% de at ~30% conversion).

Key words: chiral auxiliaries, chiral resolution, molecular recognition, stereoselectivity

The resolution and synthesis of pharmaceutically important[1] enantiomerically pure 2-phenylpropionic acid and its derivatives are well documented.[2] Since 2000, we have been interested in the mutual, kinetic, and parallel resolutions[3] of pentafluorophenyl 2-phenylpropionate (*rac*)-**2**[4] and related derivatives using Evans' 4-phenyloxazolidin-2-one [(*R*)-**1**, Scheme 1].[5] Deprotonation of oxazolidin-2-one (*R*)-**1** (1 equiv) with *n*-BuLi (1.1 equiv) at –78 °C, followed by the addition of pentafluorophenyl 2-phenylpropionate (*rac*)-**2** (1 equiv), gave after 2 hours the corresponding oxazolidin-2-one adducts (*S*,*R*)-*syn*-**3** and (*R*,*R*)-*anti*-**3** in 39% and 16% yields, respectively, with a diastereomeric ratio of 70:30 (Scheme 1).[5] The level of diastereocontrol was poor (40% de) due to competitive formation of the minor diastereomer under these reaction conditions. This level of diastereocontrol for (*S*,*R*)-*syn*-**3** could be improved to 84% de using an excess of the racemic pentafluorophenyl 2-phenylpropionate [(*rac*)-**2**, 2 equiv, Scheme 1].[5]

In our attempt to improve the diastereoselective outcome of this methodology,[6] we became interested in the use of the structurally related 4-phenyloxazolidin-2-thione [(*S*)-**4**][7] as a resolving component. We now report an extension to our original methodology for the efficient resolution of

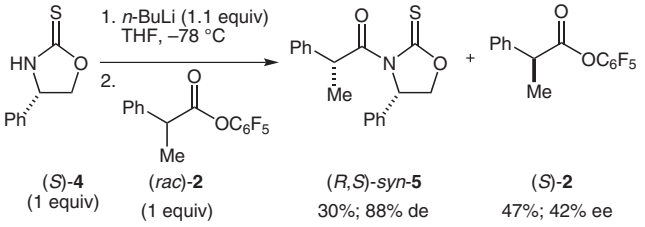


Scheme 1 Resolution of pentafluorophenyl 2-phenylpropionate [(*rac*)-**2**] using oxazolidin-2-one (*R*)-**1**

SYNLETT 2009, No. 6, pp 0960–0964
Advanced online publication: 16.03.2009
DOI: 10.1055/s-0028-1088218; Art ID: D40208ST

pentafluorophenyl 2-phenylpropionate [(*rac*)-**2**] and structurally related pentafluorophenyl active esters (*rac*)-**7**, (*rac*)-**9**, (*rac*)-**11**, (*rac*)-**13**, (*rac*)-**15**, and (*rac*)-**17**, using 4-phenyloxazolidin-2-thione [(*S*)-**4**] as the resolving agent (Scheme 2). We outline the scope and limitations of this methodology and disclose the probable reasons for the high levels of diastereocontrol.

We first investigated the resolution of pentafluorophenyl 2-phenylpropionate [(*rac*)-**2**] using an equimolar amount of 4-phenyl oxazolidin-2-thione [(*S*)-**4**, Scheme 2]. Treatment of 4-phenyloxazolidin-2-thione [(*S*)-**4**] with *n*-BuLi in THF at –78 °C, followed by addition of pentafluorophenyl 2-phenylpropionate [(*rac*)-**2**], gave after two hours the corresponding oxazolidin-2-thione adduct (*R*,*S*)-*syn*-**5**[8] in 30% yield with 88% de (Scheme 2). The level of diastereocontrol was found to be excellent [measured by ^{1}H NMR spectroscopy (400 MHz)].[9] The remaining active ester **2**[10,11] was recovered by column chromatography in 47% yield and was found to have an *S*-configuration with 42% ee (Scheme 2).[12] With this information at hand, we next investigated the diastereoselectivity of this process by altering the relative amount of the active ester (*rac*)-**2** (0.25–2 equiv). To our surprise, in all cases studied, the relative diastereoselectivity remained constant (87–90% de), whereas understandably the yields improved with an increase of active ester (*rac*)-**2** (Table 1). Intriguingly, the level of diastereocontrol remained constant irrespective of the amount of active ester (*rac*)-**2** used.[13]



Scheme 2 Resolution of pentafluorophenyl 2-phenylpropionate (*rac*)-**2** using oxazolidin-2-thione (*S*)-**4**

We next chose to investigate the temperature dependence of this resolution by the addition of a solution of lithiated oxazolidin-2-thione derived from (*rac*)-**4** (in THF) to a solution of active ester (*rac*)-**2** (in THF) at a variety of temperatures (ranging from –88 °C to 20 °C, Table 2). The overall levels of diastereoselectivity were found to be highly temperature dependent; for high yield and excel-

Table 1 Resolution of Active Ester (*S*)-**2** Using 4-Phenyloxazolidin-2-thione [(*S*)-**4**][a]

Entry	Active ester (*S*)-**2** (n equiv)	Yield (%) of product (*R*,*S*)-*syn*-**5**	de (%)
1	0.25	13	88
2	0.5	33	90
3	1	30	88
4	1.5	40	87
5	2	45	88

[a] One equiv of 4-phenyloxazolidin-2-thione [(*S*)-**4**] was used.

lent levels of molecular recognition between the oxazolidin-2-thione (*rac*)-**4** and active ester (*rac*)-**2**, the temperature was required to be at or below –78 °C. This reaction was also found to be particularly sensitive to the temperature at which the active ester (*rac*)-**2** was added. Addition of the active ester (*rac*)-**2** at room temperature [to a stirred solution of lithiated oxazolidin-2-thione (*S*)-**4**] lowered the diastereoselectivity to 74% de (after 5 min, 10% yield) but gradually increased to 86% de after cooling in the reaction vessel for 20 minutes at –78 °C (19% yield).

Table 2 Variation of Temperature and Diastereoselectivity

Temp (°C)	Product **5**	Yield (%)	de (%)
–88	(*R*,*S*)-*syn*-**5**	5	64
–78	(*R*,*S*)-*syn*-**5**	30	88
–55	(*R*,*S*)-*syn*-**5**	34	36
–10	(*S*,*S*)-*anti*-**5**	60	8
0	(*S*,*S*)-*anti*-**5**	60	8
20	(*S*,*S*)-*anti*-**5**	57	6

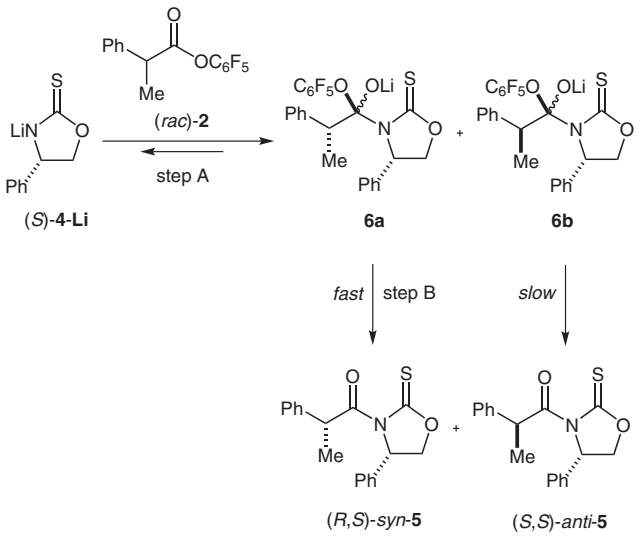
With this information at hand, we next investigated the reaction time for optimum formation of this product, (*R*,*S*)-*syn*-**5** at –78 °C. We chose to study this reaction from 1 minute [after the active ester (*rac*)-**2** was added] through to 12 hours. Somewhat surprisingly, we found that at the start of this reaction the levels of diastereoselectivity appeared to be independent of conversion up to ~30% (Table 3). Even after 12 hours, the reaction had only proceeded to 37% conversion giving the product, oxazolidin-2-thione (*R*,*S*)-*syn*-**5**, in 37% yield with 80% de (Table 3).

This outcome is possible if the reaction proceeded via a two-step process where the initial addition (step A) to give intermediates **6a**,**b** was reversible, and the elimination of lithium pentafluorophenolate (step B) to form the oxazolidin-2-thione (*R*,*S*)-*syn*-**5** was the product-determining step (Scheme 3). The relative diastereoselectivity of this process appears to be a measure of the relative rates of these addition–elimination pathways.

Table 3 Variation of Time and Diastereoselectivity

Time	Yield (%) of (*R*,*S*)-*syn*-**5**	de (%)
1 min	<5	84
5 min	10	86
10 min	15	86
20 min	19	86
1 h	26	88
2 h	32	88
12 h	37	80

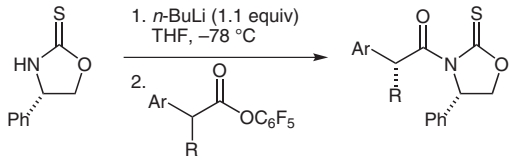
In an attempt to get a better understanding of this process, we next chose to investigate two sterically demanding active esters, pentafluorophenyl 2-phenylbutanoate [(*rac*)-**7**] and pentafluorophenyl 2-phenyl-3-methylbutanoate [(*rac*)-**9**, Table 4, entries 2 and 3)]. The de was improved to 96% [for oxazolidin-2-thione adduct (*R*,*S*)-*syn*-**8**] using pentafluorophenyl 2-phenylbutanoate [(*rac*)-**7**, Table 4, entry 2). In comparison, for the more sterically demanding pentafluorophenyl 2-phenyl-3-methylbutanoate [(*rac*)-**9**], the corresponding oxazolidin-2-thione adduct (*R*,*S*)-*syn*-**10** was not formed under our standard reaction conditions (–78 °C for 2 h and 12 h, Table 4, entries 3 and 4). In contrast, by allowing the reaction mixture to warm up to room temperature and stirring the resulting reaction mixture for 12 h, gave the oxazolidin-2-thione adduct (*R*,*S*)-*syn*-**10** in 51% yield with low de (28% de, Table 4, entry 3).



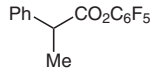
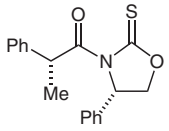
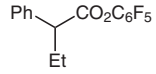
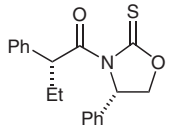
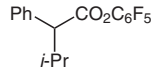
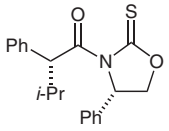
Scheme 3 Proposed mechanism for the formation of oxazolidin-2-thione (*R*,*S*)-*syn*-**5** derived from (*S*)-**4-Li**

We next investigated a series of structurally related pentafluorophenyl 2-arylpropionates (*rac*)-**11**, (*rac*)-**13**, (*rac*)-**15**, and (*rac*)-**17** (Table 5). These active esters (*rac*)-**11**, (*rac*)-**13**, and (*rac*)-**17** behaved similarly to the parent active ester pentafluorophenyl 2-phenylpropionate [(*rac*)-**2**] giving the oxazolidin-2-thiones (*R,S*)-**12** (in

Table 4 Resolution of Pentafluorophenyl Esters (*rac*)-**2**, (*rac*)-**7**, and (*rac*)-**9** Using Oxazolidin-2-thione (*S*)-**4**



(*S*)-**4** (1 equiv) (*rac*)-**2**,**7**,**9** (1 equiv) (*R*,*S*)-*syn*-**5**,**8**,**10**

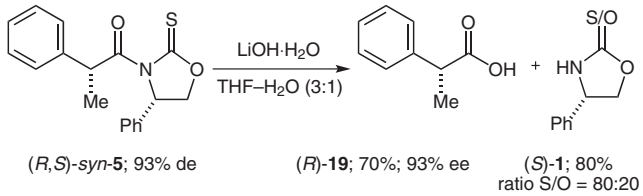
Entry	Active ester	Product	de (%)	Yield (%)	Recovered active ester
1	 (*rac*)-**2**	 (*R*,*S*)-*syn*-**5**	94	30	(*S*)-**2**, 47%, 42% ee
2	 (*rac*)-**7**	 (*R*,*S*)-*syn*-**8**	96	31	(*S*)-**7**, 40%, 54% ee
3			–	–[a]	
4			–	–[b]	
5	(*rac*)-**9**	(*R*,*S*)-*syn*-**10**	28	51[c]	(*S*)-**9**, 0%

[a] Reaction conditions: –78 °C, 2 h.
[b] Reaction conditions: –78 °C, 12 h.
[c] Reaction conditions: –78 °C, r.t., 12 h.

26% yield with 88% de), (*R*,*S*)-**14** (in 30% yield with 92% de), and (*R*,*S*)-**18** (in 30% yield with 86% de), respectively, in similar yields (26–30%) and diastereocontrol (86–92% de, Table 5, entries 1, 2, and 4). The remaining pentafluorophenyl 2-(4-chlorophenyl)propionate [(*rac*)-**15**] gave the corresponding oxazolidin-2-thione (*R*,*S*)-*syn*-**16** in 28% yield with significantly lower levels of diastereocontrol (64% de, Table 5, entry 3).[14]

Access to enantiomerically enriched 2-phenylpropionic acid [(*R*)-**19**, with 93% ee][15] was achieved in 70% yield by lithium hydroxide–hydrogen peroxide mediated hydrolysis of oxazolidin-2-thione (*R*,*S*)-*syn*-**5** (Scheme 4). The oxazolidin-2-thione (*S*)-**1** was recovered in 80% yield with 80% sulfur retention (Scheme 4).

In conclusion, we have shown that a series of structurally related pentafluorophenyl 2-aryl and phenyl propionates, such as (*rac*)-**2**, can be efficiently resolved using 4-phenyloxazolidin-2-thione [(*S*)-**4**] in good yield with high levels of diastereomeric excess.[16] The levels of diastereoselectivity were found to be independent of conversion (from 5–30%) and suggests the diastereoselective addition of the lithiated 4-phenyloxazolidin-2-thione [(*S*)-**4**-**Li**] to the active ester (*rac*)-**2** was reversible, thus allowing the less reactive enantiomer of the active ester (*S*)-**2** to be returned. Competitive elimination of the resulting tetrahedral intermediates **6a**,**b** leads to the products (*R*,*S*)-*syn*-**5** and (*S*,*S*)-*anti*-**5** in a diastereomeric ratio of 94:6 (88% de). We are currently investigating the scope and limitation of this resolution process, and the results will be reported in due course.



(*R*,*S*)-*syn*-**5**; 93% de (*R*)-**19**; 70%; 93% ee (*S*)-**1**; 80% ratio S/O = 80:20

Scheme 4 Hydrolysis of oxazolidin-2-thione (*R*,*S*)-*syn*-**5**

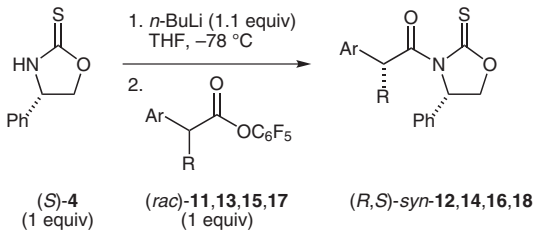
Acknowledgment

We are grateful to the EPSRC (to E.C.) for a studentship, the Saudi Government for financial support (to N.A.S.), and the EPSRC National Mass Spectrometry Service (Swansea) for accurate mass determinations.

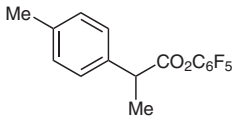
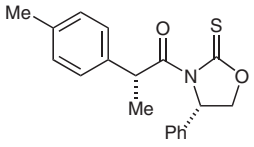
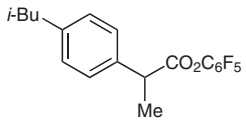
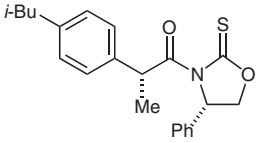
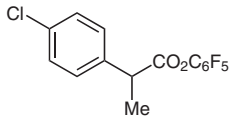
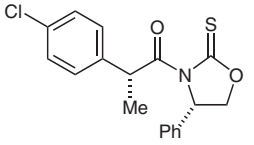
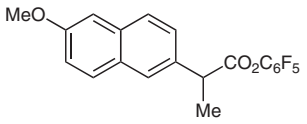
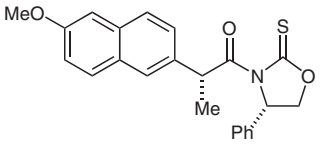
References and Notes

(1) Nerurkar, S. G.; Dighe, S. V.; Williams, R. L. *J. Clin. Pharmacol.* **1992**, *32*, 935.
(2) (a) Sonawane, H. R.; Bellur, N. S.; Ahuja, J. R.; Kulkarni, D. G. *Tetrahedron: Asymmetry* **1992**, *3*, 163. (b) Fuji, K.; Node, M.; Tanaka, F.; Hosoi, S. *Tetrahedron Lett.* **1989**, *30*, 2825. (c) Corriu, J. P.; Masse, J. P. *J. Chem. Soc., Chem. Commun.* **1972**, 144. (d) Tamao, K.; Sumitani, K.; Kumada, M. *J. Am. Chem. Soc.* **1972**, *94*, 4374. (e) Hayashi, T.;

Table 5 Resolution of Pentafluorophenyl Esters (*rac*)-**11**, (*rac*)-**13**, (*rac*)-**15**, and (*rac*)-**17** Using Oxazolidin-2-thione (*S*)-**4**



(*S*)-**4** (1 equiv) (*rac*)-**11**,**13**,**15**,**17** (1 equiv) (*R*,*S*)-*syn*-**12**,**14**,**16**,**18**

Entry	Active ester	Product	de (%)	Yield (%)	Recovered active ester
1	 (*rac*)-**11**	 (*R*,*S*)-*syn*-**12**	88	26	(*S*)-**11**, 45%, 42% ee
2	 (*rac*)-**13**	 (*R*,*S*)-*syn*-**14**	92	30	(*S*)-**13**, 47%, 54% ee
3	 (*rac*)-**15**	 (*R*,*S*)-*syn*-**16**	64	28	(*S*)-**15**, 36%, 48% ee
4	 (*rac*)-**17**	 (*R*,*S*)-*syn*-**18**	86	30	(*S*)-**17**, 50%, 44% ee

Konishi, M.; Fukushima, M.; Kanehira, K.; Hioki, T.; Kumada, M. *J. Org. Chem.* **1983**, *48*, 2195. (f) Larsen, R. D.; Corley, E. G.; Davis, P.; Reider, P. J.; Grabowski, E. J. J. *J. Am. Chem. Soc.* **1989**, *111*, 7650. (g) Alper, H.; Hamel, N. *J. Am. Chem. Soc.* **1990**, *112*, 2803. (h) Ohta, T.; Takaya, H.; Kitamura, M.; Nagai, K.; Noyori, R. *J. Org. Chem.* **1987**, *52*, 3174.

(3) For reviews, see: (a) Eames, J. *Angew. Chem. Int Ed.* **2000**, *39*, 885. (b) Eames, J. In *Organic Synthesis Highlights*, Vol. 5; Wiley-VCH: Weinheim, **2003**, Chap. 17, 151. (c) Dehli, J. R.; Gotor, V. *Chem. Soc. Rev.* **2002**, *31*, 365. (d) Dehli, J. R.; Gotor, V. *ARKIVOC* **2002**, *(v)*, 196.

(4) (a) Coumbarides, G. S.; Dingjan, M.; Eames, J.; Flinn, A.; Motevalli, M.; Northen, J.; Yohannes, Y. *Synlett* **2006**, 101. (b) Boyd, E.; Chavda, S.; Eames, J.; Yohannes, Y. *Tetrahedron: Asymmetry* **2007**, *18*, 476.

(5) (a) Coumbarides, G. S.; Dingjan, M.; Eames, J.; Flinn, A.; Northen, J.; Yohannes, Y. *Tetrahedron Lett.* **2005**, *46*, 2897. (b) Yohannes, Y. *PhD Thesis*; University of London: UK, **2004**.

(6) Chavda, S.; Coulbeck, E.; Dingjan, M.; Eames, J.; Flinn, A.; Northen, J. *Tetrahedron: Asymmetry* **2008**, *19*, 1536.

(7) (a) Delaunay, D.; Toupet, L.; Corre, M. L. *J. Org. Chem.* **1995**, *60*, 6604. (b) Wu, Y.; Yang, Y.-Q.; Hu, Q. *J. Org. Chem.* **2004**, *69*, 3990.

(8) The relative configuration of this adduct was determined through stereospecific synthesis.

(9) For oxazolidin-2-thione (*S*,*S*)-*anti*-**5**, the PhCHN double doublet appeared at δ = 5.51 ppm (1 H, dd, *J* = 8.3, 3.0 Hz). Whereas, for oxazolidin-2-thiones (*R*,*S*)-*syn*-**5**, the PhCHN double doublet appeared at δ = 5.62 ppm (1 H, dd, *J* = 9.2, 6.1 Hz).

(10) Eames, J.; Chavda, S.; Coumbarides, G. S.; Dingjan, M.; Flinn, A.; Northen, J. *Chirality* **2007**, *19*, 313.

(11) Boyd, E.; Chavda, S.; Coulbeck, E.; Coumbarides, G. S.; Dingjan, M.; Eames, J.; Flinn, A.; Motevalli, M.; Northen, J.; Yohannes, Y. *Tetrahedron: Asymmetry* **2007**, *18*, 2515.

(12) The ee was determined through hydrolysis of the active ester and derivatization of the parent 2-phenylpropionic acid. For further information, see ref. 15.

(13) For the mutual kinetic resolution of active ester (*rac*)-**2** with 4-phenyloxazolidin-2-thione (*rac*)-**4**, gave the corresponding (*RS*,*SR*)-(*rac*)-*syn*-**5** in 55% yield with 96% de. For further information, see ref. 6.

(14) This lower diastereocontrol was not due to in situ racemization of active ester (*rac*)-**15** nor epimerization of the resulting oxazolidin-2-thione (*R*,*S*)-*syn*-**16** as this adduct can be made stereospecifically by addition of (*R*)-**15** to the lithiated 4-phenyloxazolidin-2-thione (*S*)-**4**-**Li**.

(15) The ee was determined by derivatisation with (*R*)-1-phenylethanol using a DMAP-mediated DCC coupling procedure.

(16) **Representative Experimental Procedure:(2*R*,4*S*)-3-(2-Phenylpropionyl)-4-phenyloxazolidin-2-thione [(*R*,*S*)-*syn*-5]**

n-Butyllithium (0.36 mL, 2.5 M in hexane, 0.90 mmol) was added to a stirred solution of 4-phenyloxazolidin-2-thione (*S*)-**4** (0.15 g, 0.84 mmol) in THF (5 mL) at –78 °C. After stirring for 1 h, a solution of pentafluorophenyl 2-phenylpropionate [(*rac*)-**2**, 0.26 g, 0.84 mmol] in THF (1 mL) was added. The resulting mixture was stirred for 2 h at –78 °C. The reaction was quenched with H_2O (10 mL). The organic layer was extracted with CH_2Cl_2 (2 × 10 mL), dried ($MgSO_4$), and evaporated under reduced pressure to give a mixture of diastereomeric oxazolidin-2-thiones *syn*-**5** and *anti*-**5** (ratio 94:6 *syn*/*anti*). The crude residue was purified by flash chromatography on SiO_2 eluting with light PE (bp 40–60 °C)–Et_2O (7:3) to give the oxazolidin-2-thione (*R*,*S*)-*syn*-**5** (77 mg, 30%) as a white solid and the pentafluorophenyl 2-phenylpropionate (*S*)-**2** (0.123 g, 47%) as a colorless liquid.

Oxazolidin-2-thione (*R*,*S*)-*syn*-**5**: R_f = 0.67 [light PE (bp 40–60 °C)–Et_2O, 1:1]; mp 87–89 °C [lit.[6] (*S*,*R*) 84–86 °C]; $[\alpha]_D^{20}$ +66.1 (*c* 3.6, $CHCl_3$) [lit. (*S*,*R*) $[\alpha]_D^{20}$ –58.3 (*c* 4.0, $CHCl_3$)]. IR ($CHCl_3$): ν_{max} = 1708 (C=O), 1216 (C=S) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.20–7.08 (6 H, m, 6 × CH, Ph^A and Ph^B), 6.94 (2 H, dt, *J* = 6.9, 1.8 Hz, 2 × CH, Ph^A), 6.88 (2 H, dt, *J* = 7.0, 1.8 Hz, 2 × CH, Ph^B), 5.98 (1 H, q, *J* = 6.9 Hz, PhC*H*CH_3), 5.62 (1 H, dd, *J* = 9.2, 6.1 Hz, PhCHN), 4.68 (1 H, t, *J* = 9.2 Hz, C$H_A$$H_B$O), 4.20 (1 H, dd, *J* = 9.2, 6.1 Hz, CH_AH_BO), 1.35 (3 H, d, *J* = 6.9 Hz, PhCHCH_3). ^{13}C NMR (100 MHz, $CDCl_3$): 185.2 (C=S), 174.8 (C=O), 139.1 and 136.9 (2 × *i*-C; 2 × Ph), 128.8,[2] 128.7,[1] 128.5,[2] 128.3,[2] 127.1[1] and 126.4[2] (10 × CH, 2 × Ph), 73.6 (CH_2O), 62.6 (PhCHN), 43.9 (Ph*C*HCH_3), 18.7 (PhCH*C*H_3). HRMS: *m/z* calcd for $C_{18}H_{18}NO_2S$ [MH^+]: 312.1053; found: 312.1054.

Pentafluorophenyl 2-phenylpropionate (*S*)-**2**: R_f = 0.63 [light PE (40–60 °C)–Et_2O, 9:1]; $[\alpha]_D^{20}$ +40.8 (*c* 4.6, $CHCl_3$) {ca. 55% ee based on lit.[10] (*S*) $[\alpha]_D^{20}$ +74.5 (*c* 4.9, $CHCl_3$); lit.[11] (*R*) $[\alpha]_D^{20}$ –75.0 (*c* 3.3, $CHCl_3$)}. IR (film): ν_{max} = 1784 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.41–7.28 (5 H, m, 5 × CH, Ph), 4.07 (1 H, q, *J* = 7.2 Hz, CH_3C*H*), 1.64 (3 H, d, *J* = 7.2 Hz, C*H*$_3$CH). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 170.6 (OC=O), 141.1 [142.40 and 139.90, 2 C, ddt, $^1J_{C,F}$ = 251.3 Hz, $^2J_{C,F}$ = 12.2 Hz, $^3J_{C,F}$ = 3.8 Hz, C(2)-F], 139.4 [140.70 and 138.18, 1 C, dtt, $^1J_{C,F}$ = 253.2 Hz, $^2J_{C,F}$ = 13.4 Hz, $^3J_{C,F}$ = 4.2 Hz, C(4)-F], 138.7 (*i*-C, Ph), 137.8 [139.05 and 136.58, 2 C, dtdd, $^1J_{C,F}$ = 249.1 Hz, $^2J_{C,F}$ = 14.5 Hz, $^3J_{C,F}$ = 5.7 Hz, $^4J_{C,F}$ = 3.1 Hz, C(3)-F], 128.9, 127.8, 127.5 (3 × CH, Ar), 125.2 (1 C, tdt, $^2J_{C,F}$ = 14.2 Hz, $^4J_{C,F}$ = 4.2 Hz, $^3J_{C,F}$ = 2.0 Hz, *i*-CO, OC_6F_5), 45.1 (PhCH), 18.5 (*C*H_3CH). ^{19}F NMR (378 MHz, $CDCl_3$): δ = –152.6 (2 F, d, $^3J_{F,F}$ = 20.9 Hz, F_{ortho}), –157.9 (1 F, t, $^3J_{F,F}$ = 20.9 Hz, F_{para}), –162.3 (2 F, t, $^3J_{F,F}$ = 20.9 Hz, F_{meta}). HRMS: *m/z* calcd for $C_{15}H_9F_5O_2$ [M^+]: 316.0517; found: 316.0514.