Asymmetric Synthesis

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Enantioselective Sulfonation of Enones with Sulfonyl Imines by Cooperative N-Heterocyclic-Carbene/Thiourea/Tertiary-Amine Multicatalysis**

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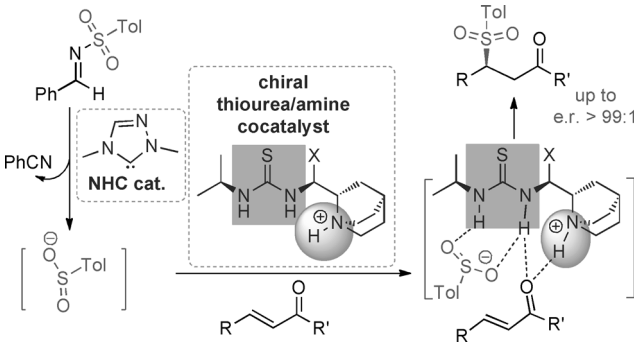
Sulfones are applied widely as versatile synthetic building blocks[1] and as biologically active agents for drugs.[2] Achiral and racemic sulfones can be synthesized by a number of methods, including the oxidation of sulfides or sulfoxides,[3] nucleophilic displacement by a sulfinic acid or its salt,[4] and reactions of sulfonyl halides with activated nucleophiles, such as organolithium species and Grignard reagents.[5] In contrast to the relatively well studied synthesis of achiral/racemic sulfones, asymmetric catalytic approaches for direct access to optically enriched sulfones are much less developed. Success in this area has mainly come from the sulfonation of allylic compounds in the presence of Pd(Ir) catalysts with chiral ligands.[6] Herein we report the first organocatalytic enantioselective sulfonation of α,β-unsaturated ketones (Scheme 1). In this reaction, two organic catalysts containing three catalytic moieties [an N-heterocyclic carbene (NHC),[7] a thiourea, and a tertiary amine] operate in a cooperative manner.[8] Specifically, the NHC-catalyzed activation of a sulfonylimine[9] with N–S bond cleavage[10] generates a sulfinic anion intermediate as a nucleophile. Through noncovalent interactions and anion recognition by the chiral thiourea[11]/tertiary amine cocatalyst, the sulfinic anion is delivered to enones in an enantioselective manner (Scheme 1).



Scheme 1. Enantioselective catalytic sulfonation of enones. Tol = *p*-tolyl.

We started by identifying sulfonation reagents and catalysts for the racemic sulfonation of enone **2a** under mild conditions. The use of *p*-toluenesulfinic acid sodium salt under various conditions in the presence of a tertiary amine, an NHC, a thiourea/tertiary-amine bifunctional catalyst, or combinations of these additives led to no detectable formation of product **3a** (Table 1, entry 1). We then accidentally found that under the catalysis of the NHC precatalyst **A1** and DABCO as a base, benzaldehyde *N*-tosylimine (**1a**) could be converted into the sulfonation product **3a** in 14% yield (Table 1, entry 2). No formation of the product was observed in the presence of only **A1** or DABCO (Table 1, entry 3). Hou and co-workers previously observed the generation of sulfinic anions from tosylimines under NHC catalysis.[10] In further studies, we found that the chiral NHC catalyst **A2** was more effective and gave **3a** in acceptable 66% yield (Table 1, entry 4). Under various conditions studied, (e.g., with different solvents), chiral NHC catalysts, such as **A2**, promoted the transformation with no enantioselectivity (Table 1, entry 4; see the Supporting Information for more examples).

The absence of enantioselectivity with chiral NHC catalysts suggests that the NHC is not covalently bonded to the substrates when the Michael addition of the sulfinic-anion equivalent to the enone occurs. In other words, the sulfinic anion is probably released from the imine substrate before its addition to the enone (Scheme 1). Mechanistically, the direct deprotonation of the imine by a base (such as DABCO or NHC) to release the sulfinic anion (Scheme 2a) is unlikely, as: 1) in the absence of an NHC, none of the product **3a** was obtained when a variety of bases were used; and 2) the acidity of the imine hydrogen atom is much weaker than that of the hydrogen atom on the triazolium ring of the NHC precatalyst, as evidenced by H/D-exchange experiments in the presence of D_2O (see the Supporting Information). Deprotonation of a "weak acid" (the imine) by a weak base (the free carbene) is unfavorable. A reasonable pathway (Scheme 2b) is a multistep process involving an analogous Breslow intermediate formed between the imine and the NHC[12] to eventually

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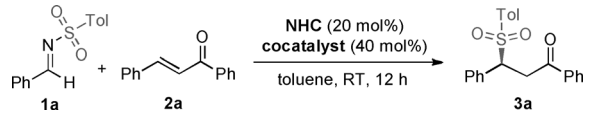
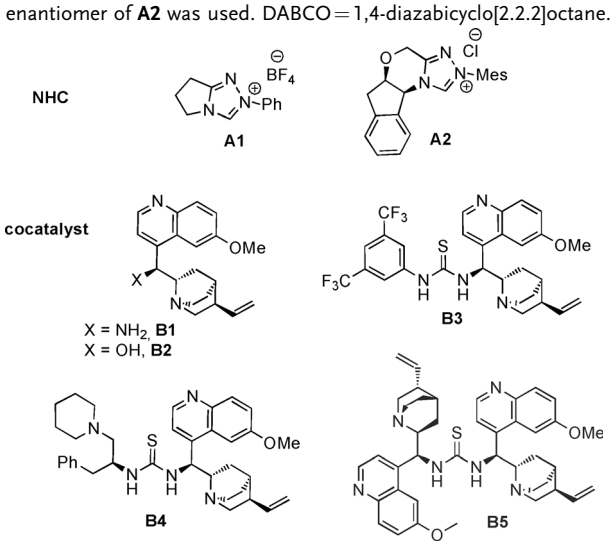
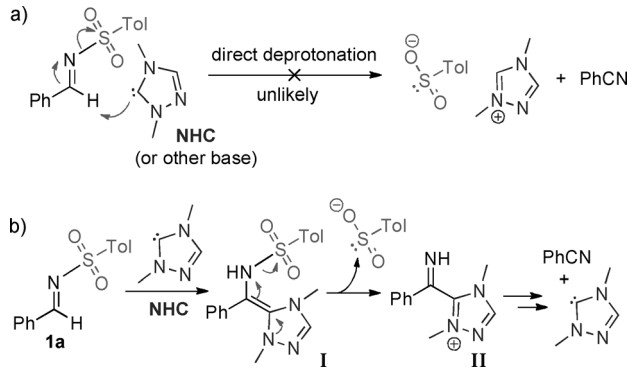
Table 1: Optimization of the reaction conditions.[a]



Entry	Conditions	Yield [%][b]	e.r.[c]
1	*p*-TolSO$_2$Na (no **1a**), various conditions	0	–
2	**A1**, DABCO	14	–
3	only **A1** or DABCO	0	–
4	**A2**, DABCO	66	50:50
5	**A1**, **B1**	18	55:45
6	**A2**, **B1**	45	52:48
7	**A2**, quinine (9-*epi*-**B2**)	36	42:58
8	**A2**, **B3**	38	70:30
9	**A2**, **B4**	79	73:27
10	**A2**, **B5** (40 mol%)	68	88:12
11	**A2**, **B5** (10 mol%), 0°C, 72 h[d]	67	96:4
12	*ent*-**A2**,[e] **B5** (10 mol%), 0°C, 72 h[d]	65	95:5
13	achiral **A1**, **B5** (40 mol%), RT, 12 h	ca. 5	57:43

[a] General conditions (unless otherwise specified): **1a** (0.10 mmol), **2a** (0.05 mmol), NHC (20 mol%), base (40 mol%), toluene (0.5 mL), room temperature (24°C), 12 h. [b] Yield of the isolated product. [c] The enantiomeric ratio was determined by HPLC on a chiral phase. [d] The reaction was carried out with 2 mL of toluene (0.025 M). [e] The enantiomer of **A2** was used. DABCO = 1,4-diazabicyclo[2.2.2]octane.





Scheme 2. Postulated pathways for the NHC-mediated generation of a sulfinic anion from an imine.

generate the sulfinic anion and release an equivalent of phenyl nitrile (PhCN, isolated experimentally). NHC–imine adducts similar to **I** (Scheme 2b) were previously observed in NHC-catalyzed reactions studied by the research groups of Rovis and Ye.[12a,b] Our attempts to detect intermediate **I** were unsuccessful, which suggests that the process to release the sulfinic anion and PhCN from **I** is facile.

Our failure to control the enantioselectivity of the reaction with NHC catalysts prompted us to explore other catalytic approaches for asymmetric induction. Hypothetically, it would be possible to control the enantioselectivity through interactions with the enone and/or the catalytically generated sulfinic anion. Thioureas are known for ion recognition of anions and for noncovalent interactions with electrophiles (such as imines and ketones), as pioneered by Jacobsen and Sigman as well as others.[11,13] Since our reaction involves both an anionic nucleophile and an α,β-unsaturated ketone electrophile, thiourea cocatalysts were chosen for further studies. Additionally, in our NHC-catalyzed step, a base catalyst is needed to deprotonate the triazolium NHC precatalyst. Therefore, a tertiary amine was incorporated as a basic moiety into the thiourea cocatalyst to generate a thiourea/tertiary-amine bifunctional catalyst.

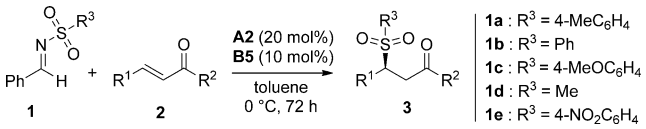
When we used the cinchona-alkaloid-type compound **B1** as a chiral base with the achiral NHC precatalyst **A1**, the reaction gave product **3a** with a low but encouraging enantiomeric ratio of 55:45 (Table 1, entry 5). This result suggested that the conjugate acid of **B1** (formed by the deprotonation of **A1** to give the free carbene) might interact with enone **2a** and/or the sulfinic anion to cause asymmetric induction. Since the reaction yields were low with achiral NHC catalysts such as **A1** (e.g., 18% yield, Table 1, entry 5), we used **A2** for further studies (Table 1, entries 6–12). With the chiral base **B1**, the reaction gave **3a** in 45% yield with e.r. 52:48 (Table 1, entry 6). The use of quinine (9-*epi*-**B2**) led to **3a** in 36% yield with e.r. 42:58 (Table 1, entry 7). When a thiourea moiety was introduced into the chiral base to give the thiourea/tertiary-amine bifunctional cocatalyst **B3**, the corresponding catalytic reaction afforded **3a** in similar yield (38%) but with a significantly higher enantiomeric ratio (70:30; Table 1, entry 8). This result clearly showed the beneficial effect of the use of thiourea/tertiary-amine cocatalysts. By the further introduction of an additional tertiary amino group into the thiourea-based catalyst (e.g. to give **B4** and **B5**), both the yield and the enantioselectivity of the reaction could be improved (Table 1, entries 9 and 10). Of several promising thiourea/tertiary-amine catalysts (see the Supporting Information), **B5** was finally found to be the most efficient: this cocatalyst mediated the formation of **3a** in 67% yield with e.r. 96:4 (Table 1, entry 11). The use of the opposite enantiomer of the NHC precatalyst **A2** under otherwise identical conditions led to a similar result (65% yield, e.r. 95:5; Table 1, entry 12), which again confirms that the chirality of the NHC has no apparent influence on the enantioselectivity of the reaction.

Although the chiral NHC catalyst alone showed no asymmetric induction, the structure of the NHC influenced the enantioselectivity induced by the chiral thiourea/tertiary-amine cocatalyst. For example, with the thiourea cocatalyst

B5, the use of NHC precatalyst **A1** gave **3a** with an enantiomeric ratio of just 57:43 (Table 1, entry 13), whereas an enantiomeric ratio of 88:12 was found when the NHC **A2** was used under otherwise identical conditions (Table 1, entry 10; see the Supporting Information for more examples). These results suggested that the nucleophilic sulfinic anion was not delivered to enones as an isolated species. Instead, electrostatic interactions between the negatively charged sulfinic anion and the positively charged triazolium NHC precatalyst[14] also played a role in the asymmetric induction.

We next examined the scope of the reaction under the optimized conditions (Table 2). Chalcone-type enones with different aromatic substituents reacted smoothly to afford the corresponding γ-ketosulfones in good yields with excellent enantioselectivity (Table 2, entries 1–14). When the tolyl

Table 2: Examples of the sulfonation reaction.[a]

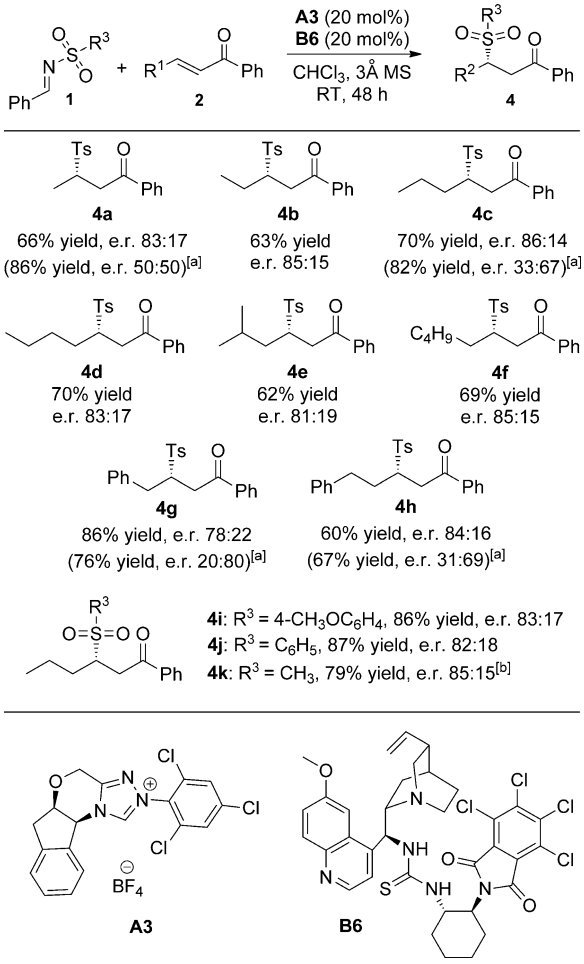


1 2 3

Entry	1	R^1	R^2	3	Yield [%]	e.r.
1[b]	**1a**	Ph	Ph	**3a**	69	96:4
2[c]	**1a**	4-$MeOC_6H_4$	Ph	**3b**	60	90:10
3	**1a**	3-$NO_2C_6H_4$	Ph	**3c**	76	89:11
4	**1a**	4-ClC_6H_4	Ph	**3d**	49	95:5
5	**1a**	4-MeC_6H_4	Ph	**3e**	54	94:6
6	**1a**	4-$NO_2C_6H_4$	Ph	**3f**	84	>99:1
7	**1a**	Ph	4-$MeOC_6H_4$	**3g**	64	97:3
8	**1a**	Ph	4-ClC_6H_4	**3h**	79	97:3
9[b]	**1a**	Ph	4-BrC_6H_4	**3i**	77	>99:1
10	**1a**	Ph	2-naphthyl	**3j**	57	91:9
11	**1a**	4-ClC_6H_4	4-ClC_6H_4	**3k**	52	99:1
12	**1a**	Ph	2-furyl	**3l**	63	95:5
13	**1b**	Ph	Ph	**3m**	52	96:4
14	**1c**	Ph	Ph	**3n**	67	92:8
15	**1d**	Ph	Ph	**3o**	44	73:27
16[c]	**1e**	Ph	Ph	**3p**	13	93:7
17	**1a**	COOEt	Ph	**3q**	50	50:50
18[c]	**1a**	Ph	Me	**3r**	30	77:23
19	**1a**	*n*Bu	Me	**3s**	58	60:40
20	**1a**	Me	Ph	**4a**	86	50:50

[a] General conditions (unless otherwise specified): as in Table 1, entry 11. [b] The reaction was carried out on a 0.5 mmol scale (with respect to **2**). [c] The reaction was carried out at room temperature (24 °C) for 24 h.

finally found that the combined use of the NHC catalyst **A3** and the bifunctional cocatalyst **B6** in chloroform provided acceptable results (Scheme 3). Much improved enantioselectivity was observed for the alkyl-substituted enones with these new catalysts and reaction conditions (e.g., for product **4a**, e.r.



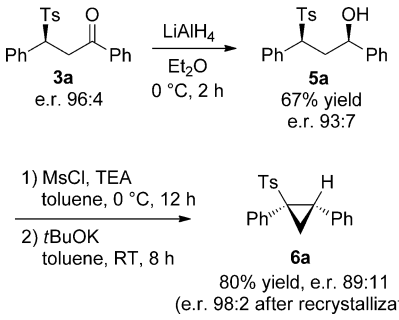
Scheme 3. Examples of the sulfonation of aliphatic enones (see the Supporting Information for detailed reaction conditions). [a] Yields and enantiomeric ratios given in the parenthesis are for reactions carried out under the conditions described in Table 1, entry 11. [b] The reaction was carried out without molecular sieves (MS). Ts = *p*-toluenesulfonyl.

group of *N*-tosylimine **1a** was replaced with an electron-withdrawing 4-$NO_2C_6H_4$ group (Table 2, entry 16), the reaction of this substrate **1e** proceeded in low yield even at room temperature. The sterically smaller *N*-mesylimine **1d** could also be used as a substrate to give the corresponding product **3o** in 44% yield with e.r. 73:27 (Table 2, entry 15). Racemization was clearly observed when the R^1 group at the β position of the enone was an ester group (Table 2, entry 17).

When the R^1 and/or R^2 group on the enone was an aliphatic substituent, the corresponding product was obtained in moderate to good yield but with lower enantioselectivity under the standard conditions (Table 2, entries 18–20). We

83:17, as opposed to e.r. 50:50 under the earlier conditions). When enone substrates with alkyl substituents on both the β and the carbonyl carbon atom were used, no product formation was observed. The use of such alkyl enones in many asymmetric catalytic reactions remains a challenge yet to be addressed.[15]

The ketone moiety of the chiral γ-ketosulfone **3a**[16] could be reduced stereoselectively with minimal erosion of the optical purity (Scheme 4).[17] The resulting alcohol **5a** was transformed into cyclopropane **6a** in good yield and with good enantioselectivity.[17] The cyclopropane is a common motif in pharmaceuticals and natural products.[18]



Scheme 4. Further transformations of the chiral sulfone **3a**. Ms = methanesulfonyl, TEA = triethylamine.

In summary, we have developed the first organocatalytic enantioselective synthesis of β-sulfonyl ketones. The sulfinic anion was generated from sulfonyl imines under NHC catalysis. The enantioselectivity of the transformations was controlled by the use of noncovalent thiourea/tertiary-amine cocatalysts. We expect that this use of noncovalent cocatalysts to control stereoselectivity can be extended to other NHC-catalyzed reactions. Evaluation of the chiral sulfone products for biological activity and further mechanistic investigations are in progress.

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[1] a) B. M. Trost, *Acc. Chem. Res.* **1978**, *11*, 453; b) P. Vogel, M. Turks, L. Bouchez, D. Marković, A. Varela-Álvarez, J. Á. Sordo, *Acc. Chem. Res.* **2007**, *40*, 931.

[2] a) W. M. J. Wolf, *Mol. Struct.* **1999**, *474*, 113; b) S. Trivedi, P. C. Patidar, P. K. Chaurasiya, *Pharma Chem.* **2010**, *2*, 369.

[3] R. W. Murray, R. Jeyararnan, M. K. Pilley, *J. Org. Chem.* **1987**, *52*, 746.

[4] J. J. Burger, T. B. R. A. Chen, E. R. DeWaard, H. O. Huisman, *Tetrahedron* **1980**, *36*, 723.

[5] H. Fukuda, F. J. Frank, W. E. Truce, *J. Org. Chem.* **1963**, *28*, 1420.

[6] a) K. Hiroi, K. Makino, *Chem. Lett.* **1986**, 617; b) B. M. Trost, M. G. Organ, G. A. O'Doherty, *J. Am. Chem. Soc.* **1995**, *117*, 9662; c) H.-J. Gais, T. Jagusch, N. Spalthoff, F. Gerhards, M. Frank, G. Raabe, *Chem. Eur. J.* **2003**, *9*, 4202; d) M. Ueda, J. F. Hartwig, *Org. Lett.* **2010**, *12*, 92; for a related study, see: e) X.-S. Wu, Y. Chen, M.-B. Li, M.-G. Zhou, S.-K. Tian, *J. Am. Chem. Soc.* **2012**, *134*, 14694.

[7] For selected reviews on NHC catalysis, see: a) D. Enders, O. Niemeier, A. Henseler, *Chem. Rev.* **2007**, *107*, 5606; b) N. Marion, S. Díez-González, S. P. Nolan, *Angew. Chem.* **2007**, *119*, 3046; *Angew. Chem. Int. Ed.* **2007**, *46*, 2988; c) A. J. Arduengo, L. I. Iconaru, *Dalton Trans.* **2009**, 6903; d) J. L. Moore, T. Rovis, *Top. Curr. Chem.* **2011**, *291*, 77; e) A. T. Biju, N. Kuhl, F. Glorius, *Acc. Chem. Res.* **2011**, *44*, 1182; f) P.-C. Chiang, J. W. Bode, *TCI MAIL* **2011**, *149*, 2; g) V. Nair, R. S. Menon, A. T. Biju, C. R. Sinu, R. R. Paul, A. Jose, V. Sreekumar, *Chem. Soc. Rev.* **2011**, *40*, 5336; h) A. Grossmann, D. Enders, *Angew. Chem.* **2012**, *124*, 320; *Angew. Chem. Int. Ed.* **2012**, *51*, 314; i) D. T. Cohen, K. A. Scheidt, *Chem. Sci.* **2012**, *3*, 53; j) X. Bugaut, F. Glorius, *Chem. Soc. Rev.* **2012**, *41*, 3511.

[8] NHCs have been combined with amine catalysts for sequential cascade reactions in which each of the catalysts mediates an independent step: a) S. P. Lathrop, T. Rovis, *J. Am. Chem. Soc.* **2009**, *131*, 13628; b) B.-C. Hong, N. S. Dange, C.-S. Hsu, J.-H. Liao, *Org. Lett.* **2010**, *12*, 4812; c) H. Jiang, B. Gschwend, Ł. Albrecht, K. A. Jørgensen, *Org. Lett.* **2010**, *12*, 5052; d) D. Enders, A. Grossmann, H. Huang, G. Raabe, *Eur. J. Org. Chem.* **2011**, 4298; e) B.-C. Hong, N. S. Dange, C.-S. Hsu, J.-H. Liao, G.-H. Lee, *Org. Lett.* **2011**, *13*, 1338; f) Y.-Z. Liu, J. Zhang, P.-F. Xu, Y.-C. Luo, *J. Org. Chem.* **2011**, *76*, 7551; g) C. B. Jacobsen, K. L. Jensen, J. Udmark, K. A. Jørgensen, *Org. Lett.* **2011**, *13*, 4790; h) C. B. Jacobsen, L. Albrecht, J. Udmark, K. A. Jørgensen, *Org. Lett.* **2012**, *14*, 5526; i) C. Ma, Z.-J. Jia, X.-J. Liu, Q.-Q. Zhou, L. Dong, Y.-C. Chen, *Angew. Chem.* **2013**, *125*, 982; *Angew. Chem. Int. Ed.* **2013**, *52*, 948.

[9] For reactions between NHCs and imines, see: a) S. Simonovic, J.-C. Frison, H. Koyuncu, A. C. Whitwood, R. E. Douthwaite, *Org. Lett.* **2009**, *11*, 245; for examples of other NHC-catalyzed reactions involving imines, see: b) M. He, J. W. Bode, *Org. Lett.* **2005**, *7*, 3131; c) G.-Q. Li, L.-X. Dai, S.-L. You, *Chem. Commun.* **2007**, 852; d) A. Chan, K. A. Scheidt, *J. Am. Chem. Soc.* **2007**, *129*, 5334; e) L, He, Y.-R. Zhang, X.-L. Huang, S. Ye, *Synthesis* **2008**, 2825; f) N. Duguet, A. Donaldson, S. M. Leckie, J. Douglas, P. Shapland, T. B. Brown, G. Churchill, A. M. Z. Slawin, A. D. Smith, *Tetrahedron: Asymmetry* **2010**, *21*, 582; g) R. De Vreese, M. D'Hooghe, *Beilstein J. Org. Chem.* **2012**, *8*, 398.

[10] D.-D. Chen, X.-L. Hou, L.-X. Dai, *J. Org. Chem.* **2008**, *73*, 5578.

[11] For pioneering studies, see: a) M. S. Sigman, E. N. Jacobsen, *J. Am. Chem. Soc.* **1998**, *120*, 4901; for selected examples, see: b) T. Okino, Y. Hoashi, Y. Takemoto, *J. Am. Chem. Soc.* **2003**, *125*, 12672; c) Y. Sohtome, A. Tanatani, Y. Hashimoto, K. Nagasawa, *Tetrahedron Lett.* **2004**, *45*, 5589; d) R. P. Herrera, V. Sgarzani, L. Bernardi, A. Ricci, *Angew. Chem.* **2005**, *117*, 6734; *Angew. Chem. Int. Ed.* **2005**, *44*, 6576; e) J. Wang, H. Li, X. Yu, L. Zu, W. Wang, *Org. Lett.* **2005**, *7*, 4293; f) S. B. Tsogoeva, S. Wei, *Chem. Commun.* **2006**, 1451; g) T. Marcelli, R. N. S. van der Haas, J. H. van Maarseveen, H. Hiemstra, *Angew. Chem.* **2006**, *118*, 943; *Angew. Chem. Int. Ed.* **2006**, *45*, 929; for selected reviews, see: h) A. G. Doyle, E. N. Jacobsen, *Chem. Rev.* **2007**, *107*, 5713; i) S. J. Connon, *Chem. Commun.* **2008**, 2499; for recent reviews on ion-pair interactions, see: j) M. Mahlau, B. List, *Angew. Chem.* **2013**, *125*, 540; *Angew. Chem. Int. Ed.* **2013**, *52*, 518; k) K. Brak, E. N. Jacobsen, *Angew. Chem.* **2013**, *125*, 558; *Angew. Chem. Int. Ed.* **2013**, *52*, 534.

[12] For examples of NHC–imine adducts, see: a) L. He, T.-Y. Jian, S. Ye, *J. Org. Chem.* **2007**, *72*, 7466; b) A. D. DiRocco, K. M. Oberg, T. Rovis, *J. Am. Chem. Soc.* **2012**, *134*, 6143; for the deprotonation of alcohols by NHCs, see: c) S. D. Sarkar, S. Grimme, A. Studer, *J. Am. Chem. Soc.* **2010**, *132*, 1190.

[13] For examples of catalysis by chiral phosphoric acids, see: a) T. Akiyama, J. Itoh, K. Yokota, K. Fuchibe, *Angew. Chem.* **2004**, *116*, 1592; *Angew. Chem. Int. Ed.* **2004**, *43*, 1566; b) D. Uraguchi, M. Terada, *J. Am. Chem. Soc.* **2004**, *126*, 5356; c) G. B. Rowland, H. Zhang, E. B. Rowland, S. Chennamadhavuni, Y. Wang, J. C. Antilla, *J. Am. Chem. Soc.* **2005**, *127*, 15696; d) D. Nakashima, H. Yamamoto, *J. Am. Chem. Soc.* **2006**, *128*, 9626; e) G. L. Hamilton, E. J. Kang, M. Mba, F. D. Toste, *Science* **2007**, *317*, 496; f) I. Čorić, B. List, *Nature* **2012**, *483*, 315; g) Z. Chen, B. Wang, Z. Wang, G. Zhu, J. Sun, *Angew. Chem.* **2013**, *125*, 2081; *Angew. Chem. Int. Ed.* **2013**, *52*, 2027; for reviews, see: h) M. Rueping, B. J. Nachtsheim, W. Ieawsuwan, I. Atodiresei, *Angew. Chem.* **2011**, *123*, 6838; *Angew. Chem. Int. Ed.* **2011**, *50*, 6706; i) L. Ren, T. Lei, L.-Z. Gong, *Chem. Commun.* **2011**, *47*, 11683; j) C. Zheng, S.-L. You, *Chem. Soc. Rev.* **2012**, *41*, 2498.

[14] A. Kumar, M. K. Muthyala, *Tetrahedron Lett.* **2011**, *52*, 5368.

[15] a) V. Nair, S. Vellalath, M. Poonoth, E. Suresh, *J. Am. Chem. Soc.* **2006**, *128*, 8736; b) P.-C. Chiang, J. Kaeobamrung, J. W. Bode, *J. Am. Chem. Soc.* **2007**, *129*, 3520; c) B. Cardinal-David, D. E. A. Raup, K. A. Scheidt, *J. Am. Chem. Soc.* **2010**, *132*, 5345; d) X. Zhao, K. E. Ruhl, T. Rovis, *Angew. Chem.* **2012**, *124*, 12496; *Angew. Chem. Int. Ed.* **2012**, *51*, 12330; e) J. Mo, R. Yang, X. Chen, B. Tiwari, Y. R. Chi, *Org. Lett.* **2013**, *15*, 50.

[16] For the racemic synthesis of β-sulfonyl ketones, see: a) B. Sreedhar, M. A. Reddy, P. S. Reddy, *Synlett* **2008**, 1949; b) A. A. Sayed, M. S. Wadia, *J. Chem. Res. Synop.* **2001**, 362.

[17] J. Skarżewski, R. Siedlecka, E. Wojaczyńska, M. Zielińska-Błajet, *Tetrahedron: Asymmetry* **2002**, *13*, 2105.

[18] a) C. J. Thibodeaux, W. Chang, H. Liu, *Chem. Rev.* **2012**, *112*, 1681; b) A. K. Kumar, *Int. J. Pharm. Pharm. Sci.* **2013**, *5*, 467.

